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(72) Inventeur/Inventor:
MCNEIL, JOHN, GB

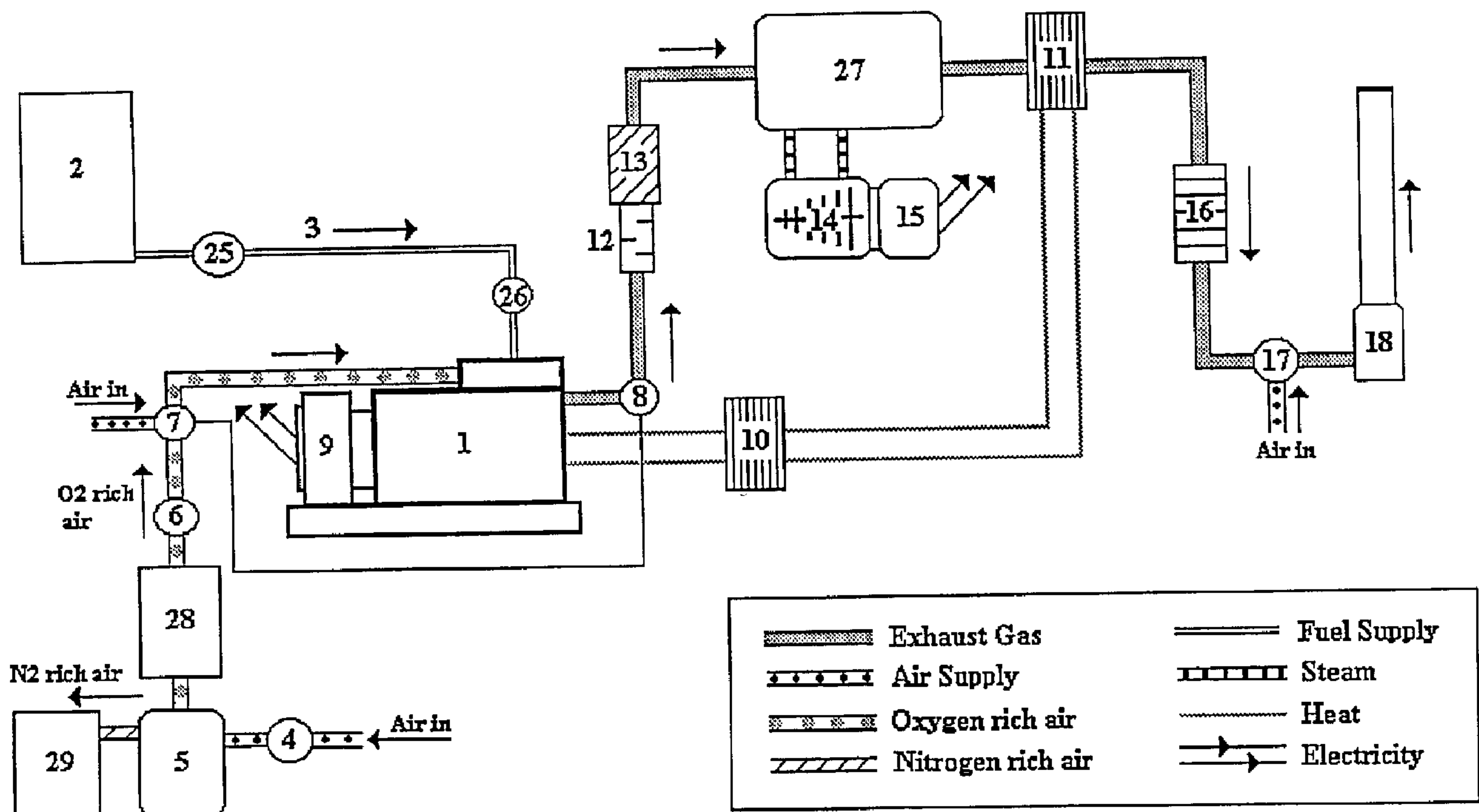
(73) Propriétaire/Owner:
OTWOEMPOWER CORP, BS

(74) Agent: OGILVY RENAULT

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(54) Title: COMBUSTION OF PYROLYSIS OIL

Pyrolysis Oil Combustion & Power Generation System



(57) Abrégé/Abstract:

The invention provides a method of combusting pyrolysis oil in a compression ignition engine wherein an enriched oxygen atmosphere is provided in the combustion chamber of the engine and using the heat and power produced by the engine to generate electricity. Pyrolysis oil is manufactured by the controlled combustion of biomass matter in an inert atmosphere. Pyrolysis oils have low calorific values and poor ignition qualities.

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(71) Applicant (*for all designated States except US*): **FINCH INTERNATIONAL LIMITED** [IE/IE]; 101 Furry Park Road, Howth Road, Dublin 5 (IE).

(72) Inventor; and

(75) Inventor/Applicant (*for US only*): **MCNEIL, John** [GB/GB]; 1 The Gallops, Vigo Village, Meopham, Gravesend, Kent DA13 0SS (GB).

(74) Agents: **LECKEY, David** et al.; Frank B. Dehn & Co., 179 Queen Victoria Street, London EC4V 4EL (GB).

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(54) Title: COMBUSTION OF PYROLYSIS OIL

(57) Abstract: The invention provides a method of combusting pyrolysis oil in a compression ignition engine wherein an enriched oxygen atmosphere is provided in the combustion chamber of the engine and using the heat and power produced by the engine to generate electricity. Pyrolysis oil is manufactured by the controlled combustion of biomass matter in an inert atmosphere. Pyrolysis oils have low calorific values and poor ignition qualities.

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COMBUSTION OF PYROLYSIS OIL

The present invention relates to a method of combusting pyrolysis oil in a standard high-speed compression ignition engine, and using the heat and power produced by the engine to generate electricity. Pyrolysis oil is manufactured by the controlled combustion of biomass matter in an inert atmosphere. Pyrolysis oils have low calorific values and poor ignition qualities.

High-speed compression ignition engines are fuel specific and only tend to operate efficiently on the petrochemical-based oils that have been designed for this type of engine. The formulation of these mineral fuels is carefully controlled to ensure that they combust reliably in high-speed compression ignition engines.

Carbon dioxide is emitted into the atmosphere when fossil-based fuels are combusted. Carbon dioxide is a greenhouse gas and it is now widely accepted that the build up of this gas in the atmosphere could be a major cause of global warming.

An alternative to fossil fuels would be to use oils derived from renewable biomass sources. One such alternative is pyrolysis oil, which is manufactured by the controlled combustion of plant material, such as wood chips, straw or grasses, in an inert atmosphere. "Pyrolysis oil" as referred to herein is not truly an "oil" as such and is sometimes referred to by those skilled in the art as "pyrolysis fuel" or "pyrolysis biofuel" as well.

The carbon dioxide that is emitted during the combustion of pyrolysis oil was recently sequestered from the atmosphere by the plants used as the raw material to produce the oil. These plants can be regrown after cropping and they will reabsorb carbon dioxide from the atmosphere. The carbon dioxide released during the combustion of pyrolysis oil is therefore not a net contributor towards the greenhouse effect.

A major limitation to the use of pyrolysis oil, as a replacement for petrochemical-based fuels, is that the oil is of relatively poor quality and difficult to ignite.

The composition of pyrolysis oil is very different from mineral oils, and it even differs considerably from other potential renewable non-fossil liquid fuels such as vegetable oils and animal fats.

Diesel fuel oil consists of a combustible mixture of alkanes and aromatic compounds. Pyrolysis oil, however, is a much more diverse and complex mixture of chemicals, typically comprising of lignin, aldehydes, carboxylic acids, carbohydrates, ketones, phenols, alcohols, water and char material. Pyrolysis oil typically has a high and acidic moisture content, a low calorific value and poor ignition qualities. The high moisture content in particular means that pyrolysis oil is difficult to ignite and combust. In addition to its low calorific value and poor quality as a fuel, pyrolysis oil may typically have a water content of from about 15 to 30%, and normally the water content is about 25%. The properties of diesel fuel oil and typical pyrolysis oil are compared in Table 1.

Table 1

Typical Properties of Diesel Oil and Pyrolysis Oil

Property	Diesel Oil	Pyrolysis Oil
Calorific Value MJ/kg	43	17
Density g/cm ³	0.83	1.20
Acidity pH	Neutral	2.5
Moisture Content %	Nil	25
Composition Mass %	C=86; H=14	C=42; H=8; O=50

The design and method of operation of compression ignition engines has been established for many years. Liquid fuel is injected into air that has been compressed by a piston travelling up a cylinder, and the fuel and air mixture is further compressed until the temperature is high enough to ignite the fuel. This leads to a rapid increase in temperature and pressure inside the combustion chamber, which forces the piston back down the cylinder on its power stroke.

The engine manufacturer will normally supply a specification rating for the engine including a recommended power output and optimum speed setting for continuous operation of the engine. This is based on a specific type of fuel i.e. diesel oil for a compression ignition engine. The engine is not designed to run on other types of fuel. Often a maximum power output (at the optimum speed) is also specified, and beyond this level it is expected that inefficient combustion and undesirable black smoke production would occur.

The fuel for this type of engine needs the appropriate ignition properties to be able to ignite by means of compression only, and the formulation of conventional diesel mineral oil is carefully controlled to achieve these qualities.

For fuels that are more difficult to ignite, the alternative to compression ignition is to use a more complicated internal combustion engine design that incorporates either a pilot or a spark ignition system in the engine to initiate ignition of the fuel.

A combustion trial was carried out in the laboratory using a Lister-Petter high-speed, twin cylinder, four-stroke diesel engine, with direct fuel injection and a nominal capacity of one litre, and using typical pyrolysis oil as fuel.

The pyrolysis oil had been manufactured from a pine wood chip feedstock, and had a moisture content of 24.6 %, with a pH of 2.3, and a calorific value of 17 MJ/kg. Char and ash particles suspended in the oil that were above a certain size, for example greater than 15 microns, would block the fuel injectors of the engine. These were removed by centrifuging the oil at 2500 rpm, and then utilising only the clear top layer from the centrifuged liquor as the fuel for the engine. Alternative techniques, such as filtration or pulverisation, could also be used to remove or reduce the larger sized particulates present in the oil, prior to injection into the engine.

The combustion trial, under normal operating conditions, confirmed that the pyrolysis oil would not reliably ignite by means of compression only in the Lister-Petter high-speed test engine.

Attempts have been made to burn pyrolysis oil in compression ignition engines by using a pre-ignition means eg. pre-ignition with diesel oil. Spark ignition engines have also been tried.

The potential for using pyrolysis oil as a fuel would be greatly improved if the crude oil could be combusted effectively in a standard, high-speed diesel engine, without the need for either a special means of ignition or expensive modifications to the composition of the oil to improve its ignition qualities.

The present invention seeks to provide an improved method of combusting pyrolysis oil using a standard compression ignition engine. It has surprisingly been found that this can

be achieved by providing an enriched oxygen atmosphere in the combustion chamber of the engine and then running the engine at its optimum speed. From a first broad aspect, therefore, the invention provides a method of combusting pyrolysis oil in a compression ignition engine wherein an enriched oxygen atmosphere is provided in the combustion chamber of the engine.

Operating the engine under these conditions enables the pyrolysis oil to self ignite under the heat of compression only and then combust effectively and cleanly.

Using an enriched oxygen atmosphere inside the combustion chamber of internal combustion engines has been studied before. However, past research has been limited in scope and has concentrated on conventional petrochemical-based fuels, in combination with oxygen enrichment, as a means of reducing the environmental pollution associated with engines that are used for transport applications.

There is no evidence that oxygen enrichment has been considered to aid the combustion in compression ignition engines of low calorific, biomass based fuels, such as pyrolysis oil, which consist of a complex mixture of chemicals having poor ignition qualities.

It will be appreciated that the invention also extends to a combustion system for operation in accordance with the invention. Viewed from a further aspect therefore, the invention provides a combustion system comprising of a compression ignition engine, a means for supplying an enriched oxygen atmosphere to the combustion chamber of said engine, and a means to supply the liquid pyrolysis fuel to said combustion chamber.

The composition of different pyrolysis oils varies and is dependent on the biomass feedstock from which the oil is made and the manufacturing technique used to produce the oil. However one factor which is peculiar to pyrolysis oil is the high water content, as mentioned above. The method of the invention can surprisingly be employed to combust pyrolysis oil having a high water content e.g. above 10%, especially 15 to 30% water. The level of oxygen enrichment would be dependent on the specific composition of the fuel. Combustion tests with the trial pyrolysis oil suggested that generally, the level of oxygen enrichment would preferably be between 4% and 6% above normally aspirated conditions (25% oxygen, 75% nitrogen and 27% oxygen, 73% nitrogen respectively). However,

pyrolysis oils that have very poor ignition qualities may require an oxygen concentration greater than 6% above normal in order to initiate ignition of the fuel. The present invention may thus also provide for the efficient combustion of pyrolysis oils of different compositions by controlling the level of oxygen enrichment in the combustion chamber of the engine to
5 suit individual oil specifications and provide optimum combustion conditions.

In general, the engine operating conditions, including the level of oxygen in the air, will be set at an optimum level determined by the quality of fuel. All the engine operating parameters are monitored and small adjustments in any one of them may be desirable to maintain efficient and smooth running of the engine.

10 The level of carbon monoxide (CO), oxides of nitrogen (NO_x) and the exhaust temperature in the exhaust gas stream may also be measured.

In particular, the carbon monoxide level in the exhaust gas stream is a good indicator of efficient combustion. Thus if carbon monoxide levels increase, the oxygen concentration of the inlet air stream may be adjusted to compensate so that carbon monoxide is returned
15 to the desired level. Any such variation in exhaust gas emission may be caused for example by differences in the composition of the fuel during engine operation.

In the case of pyrolysis oil, it may be particularly desirable to control the oxygen concentration of the inlet gas and other operating conditions, in dependence upon an analysis of the CO level in the exhaust gas stream. This is because the composition and quality of the
20 pyrolysis oil may vary considerably from one batch to the next and even within the same batch. It is therefore generally desirable to predetermine an optimum or desired level of CO in the exhaust gas stream which corresponds to an optimum or desired efficiency of combustion, and to adjust other engine operating parameters such as the oxygen inlet concentration in order to maintain the desired CO concentration in the exhaust gas stream.

25 The oxygen level can be adjusted manually or electronically, and may conveniently be controlled in dependence on the analysis of carbon monoxide levels in the exhaust gas stream.

Using an enriched oxygen atmosphere in the combustion chamber, to aid the combustion of the pyrolysis oil, results in an increased emission level of nitrogen oxides,

when compared to the combustion of diesel oil under naturally aspirated conditions. The nitrogen oxides in the exhaust gas can be abated down to an acceptable environmental level by means, for example, of catalytic reduction with ammonia.

The oxygen or oxygen rich air can be supplied by a number of commercially available means, including gas separation membranes, pressure swing adsorption, vacuum swing adsorption and cryogenic systems. A particularly surprising benefit of the invention is that the gas separation system employed will also produce a supply of nitrogen or nitrogen rich air, which can be used to provide the inert atmosphere in the pyrolysis oil manufacturing process. A complete system including both the air separation module and the pyrolysis oil combustion unit on the same site as the pyrolysis oil manufacturing plant is therefore especially advantageous. The ability to have a complementary use for the separated gases eliminates the need for two different gas separation systems and results in a cost effective gas supply to both the pyrolysis and the combustion processes.

Hence a preferred aspect of the invention is a method of combusting pyrolysis oil in a compression ignition engine wherein an enriched oxygen atmosphere is provided in the combustion chamber of the engine, wherein a gas separator provides oxygen or oxygen enriched air for the combustion atmosphere and also residual nitrogen or nitrogen rich air, the nitrogen or nitrogen rich air being used to provide an inert atmosphere in a pyrolysis oil manufacturing process. From a further aspect, the invention also provides a system comprising a compression ignition engine; a gas separation system for producing oxygen or oxygen enriched air and nitrogen or nitrogen enriched air; and a pyrolysis oil production plant; the oxygen or oxygen enriched air produced by the separator being supplied to the engine and the nitrogen or nitrogen enriched air being supplied to the pyrolysis oil production plant.

Heat taken from the engine cooling system and from the hot exhaust gas, as well as steam from the steam boiler, can also be utilised within the pyrolysis oil manufacturing process.

Also provided is a method of producing energy from biomass, comprising the combustion of plant material in an inert atmosphere to produce pyrolysis oil and the

combustion of said pyrolysis oil in a compression ignition engine in an enriched oxygen atmosphere.

Preferably, the inert atmosphere is nitrogen or a nitrogen-containing mixture of gases e.g. nitrogen-rich air and even more preferably the nitrogen is provided by an air separation unit which also supplies oxygen for the oxygen-enriched combustion atmosphere.

The present invention will have particular application in the commercial generation of electricity. Accordingly, a preferred aspect of the invention includes a method of generating power wherein an engine operating in accordance with the invention is coupled mechanically to an electrical power generating device. Furthermore, the heat from the engine can be used for localised heating purposes and/or to produce steam to drive a steam turbine, which in turn drives a further electrical generating device. In a system comprising a pyrolysis oil production plant, the heat may be used in the pyrolysis process.

Viewed from yet a further aspect, the invention provides an electrical power generating system comprising a generator coupled to an engine, said engine being able to combust poor quality pyrolysis liquid fuel by means of an enriched oxygen atmosphere in the combustion chamber of the engine.

The invention will now be described by way of example with reference to the following example and to the accompanying drawings, in which:

Figure 1 shows a schematic illustration of a cylinder of a compression ignition engine.

Figure 2 shows a schematic illustration of a system to generate electricity that utilises pyrolysis oil as the fuel in a compression ignition engine.

Figure 3 shows a schematic illustration of a process to manufacture the pyrolysis oil that utilises the product streams available from the combustion system.

Figure 4 shows the difference in smoke density of the exhaust gases when diesel oil is burnt at 9 kWe power in 21% oxygen (air) as compared against combustion of pyrolysis oil in 26% oxygen-enriched air at 8 kWe power.

Example

To confirm that pyrolysis oil could be effectively combusted in a compression ignition engine, with the aid of an enriched oxygen atmosphere in the combustion chamber, practical trials were carried out in the laboratory using the Lister-Petter test engine.

5 The engine was run at its point of maximum thermal efficiency that is when the maximum Brake Mean Effective Pressure was achieved throughout the engine revolution range. The best operating BMEP was found to occur at a speed of 2300 rpm. The engine was operated in a special test rig, where the mechanical load consisted of a high power direct current motor with a variable field voltage.

10 The engine manufacturer recommended that the most favourable power output, when running continuously at 2300 rpm and using diesel oil as fuel, was between 8 and 9-kWe. To establish the normal engine operating parameters, the engine was first run naturally aspirated (21% oxygen, 79% nitrogen) at a power output of 8.5 kWe using regular diesel oil as fuel. The exhaust temperature was measured and the exhaust gas was analysed for carbon
15 monoxide, oxides of nitrogen and smoke opacity.

The engine was then run at a power output of 8.5 kWe using the pyrolysis oil as fuel and an enriched oxygen atmosphere in the combustion chamber that was 5% above normal (26% oxygen, 74% nitrogen).

20 Again the exhaust emissions of carbon monoxide and oxides of nitrogen, the exhaust temperature and the opacity of the smoke from the engine were measured.

Under this enriched oxygen condition of 5% above normal it was established that the pyrolysis oil would self ignite by means of compression only.

The results of the trial runs with diesel oil and pyrolysis oil are compared in Table 2. For ease of comparison most of the results are given relative to naturally aspirated diesel
25 oil at 8.5 kWe power output.

Table 2
Engine Trials Using Pyrolysis Oil and Diesel Oil

Property	Diesel Oil 21% Oxygen	Pyrolysis Oil 26% Oxygen
Actual Power Output kWe	8.5	8.5
Power Output Relative	1.0	1.0
Carbon Monoxide Emission Relative	1.0	0.46
Nitrogen Oxides Emission Relative	1.0	2.91
Actual Exhaust Temperature °C	428	409

The presence of carbon monoxide in the exhaust gas is a sign of incomplete combustion and the level of carbon monoxide provides a good indication of the efficiency of the combustion process. Because of the constituents in pyrolysis oil (aldehydes, carboxylic acids, ketones and phenols), it is important that the pyrolysis oil is effectively combusted so that the exhaust gas emitted from the engine is as unpolluted as possible.

The results in Table 2 show that the method of the invention provided very effective combustion of the pyrolysis oil. The carbon monoxide emitted during the oxygen-enriched combustion of the pyrolysis oil was about 50% less than the level produced with naturally aspirated diesel oil.

The carbon monoxide concentration was in fact so low that the engine could probably have been operated at a power output much higher than 8.5 kWe without producing an unacceptable level of carbon monoxide in the exhaust gas stream.

The smoke coming from the engine when combusting the pyrolysis oil under enriched oxygen conditions was clear, and the level of particulate matter in the smoke was significantly less than in the smoke emitted when running naturally aspirated diesel oil. This provided further confirmation of the effective combustion of the pyrolysis oil. This is illustrated in Figure 4 from which it can be seen that the exhaust gas from pyrolysis oil combustion was almost completely colourless, in contrast to the exhaust smoke from diesel

oil combustion which was visibly black and dirty.

With reference to Figures 1 and 2, fuel 3 from storage tank 2 is pumped by pump 25 via a control valve 26 to the fuel injector 22 of a compression ignition engine 1. The control valve 26 regulates the rate of fuel injection dependent on an analysis by sensors that monitor the engine performance.

Air is pumped by pump 4 into a gas separation unit 5. Oxygen or oxygen rich air from the gas separation unit 5 is transferred to a storage tank 28. The oxygen or oxygen rich air is pumped by pump 6 from tank 28 to control valve 7, where it is mixed with normal atmospheric air to the required enriched oxygen composition to provide optimum engine operating conditions. The outlet of the control valve 7 is connected to the air intake manifold of the engine 1.

The nitrogen or nitrogen rich residual air from the gas separation unit 5 is transferred to a storage tank 29.

The oxygen rich air is introduced to the combustion chamber 19 of the engine cylinder 20 via the air inlet valve 21 in the cylinder head of the engine and the air is compressed by piston 23 travelling up the cylinder.

Pyrolysis oil is injected into the combustion chamber 19 by injector valve 22. As the piston 23 continues on its compression stroke, the fuel ignites, the temperature and pressure in the combustion chamber 19 rise rapidly and the piston 23 is forced back down the cylinder 20 on its power stroke.

The exhaust gas valve 24 opens to allow the exhaust gases left from the combustion process to be expelled when the piston 23 returns up the cylinder 20 on its exhaust stroke. Sensor 8, which is linked to control valve 7, continually analyses the composition of the exhaust gas stream for example the CO concentration leaving the engine, so that valve 7 can adjust the level of oxygen concentration in the engine air supply to provide optimum combustion conditions if necessary.

The engine 1 powers a generator 9 to produce electricity. The engine cooling system is connected to a heat exchange unit 10 so that heat from the engine can be used for heating purposes, in conjunction with heat taken from the hot exhaust gas by heat exchanger 11.

The exhaust gas stream passes through a silencer 12 and is then treated in an abatement unit 13 where excessive levels of oxides of nitrogen are reduced by catalytic reduction with ammonia. The hot exhaust gas is used to raise steam in boiler 27. Steam from boiler 27 is supplied to a steam turbine 14, which drives a further generator 15 to produce more electricity. Excess steam from boiler 27 can be used for other purposes.

After leaving the heat exchanger 11 the exhaust gas is cleaned in a bag filter 16 to remove particulates that may be present in the exhaust gas stream. The exhaust gas is then diluted with air by an induced draft fan 17 and vented to the atmosphere through flue stack 18.

The pyrolysis oil manufacturing process can utilise product streams from the combustion system as illustrated with reference to Figure 3.

Organic matter 39, such as wood chips, is fed to a processing plant 40 where it is chopped to size and dried by heat 34 supplied from the heat exchangers 10 and 11 in the combustion system. The dried material 41 is fed to a hopper 42.

Nitrogen or nitrogen rich air from the gas separation unit 5 that is stored in tank 29 is fed by pump 52 into the dried material 41 and they are blown together onto the bed of the pyrolysis reactor 43. More nitrogen from tank 29 is pre-heated in a chamber 44, by heat 34 from heat exchangers 10 and 11, and is used to fluidise the bed of the reactor.

Further heat 34 for the pyrolysis reaction is supplied from heat exchangers 10 and 11, along with hot steam from the steam boiler 27, to the reactor 43. Char product from the reaction process is removed at a cyclone unit 45. The char is dried in a drying unit 46 using heat 34 from heat exchangers 10 and 11 and hot steam. The dry char is collected for use as a soil conditioner.

The hot pyrolysis gas, which includes water vapour, is condensed at a water-cooled condenser 47 and the liquid oil residues are pumped by pump 48 to an oil separation / filtration unit 49. The separated filtered oil is stored in tank 2 for use as fuel in the compression ignition engine 1.

Residual pyrolysis gas from the condenser 47, which mainly consists of nitrogen, carbon dioxide and a small amount of carbon monoxide, is filtered at bag filter 50. The gas

is vented to the atmosphere through flue 18 after being mixed with the exhaust gas from the engine and diluted with air by the induced draft fan 17.

From the above, it will be seen that the present invention enables pyrolysis oil, a low calorific fuel comprising of a complex mixture of chemicals with poor ignition qualities, to be effectively and cleanly combusted in a standard design of high-speed compression ignition engine. This is achieved by introducing an enriched oxygen atmosphere to the combustion chamber of the engine, igniting the pyrolysis oil by means of compression only and running the engine at its optimum speed. Pyrolysis oil is a renewable, non-fossil fuel manufactured from biomass material. The heat and power produced by the engine can therefore be used to generate electricity without emitting exhaust gases to the atmosphere that significantly add to the greenhouse effect.

Although the research was carried out using a high-speed engine, the method of the invention would also be applicable to low and medium-speed compression ignition engines. These types of engine usually have larger cylinder bores than high-speed engines, however, their method of providing compression ignition of fuels is similar.

Claims

1. A method of combusting liquid pyrolysis oil in a compression ignition engine said pyrolysis oil being
5 derived from biomass material, wherein an enriched oxygen atmosphere is provided in a combustion chamber of the engine thereby enabling the pyrolysis oil to self ignite under heat of compression only, and wherein oxygen enrichment of the enriched oxygen atmosphere is
10 controlled in dependence on an analysis of exhaust gases emitted from said engine.
2. A method as claimed in claim 1, wherein the oxygen enrichment is controlled in dependence on carbon
15 monoxide levels in the exhaust gas stream.
3. A method as claimed in claim 2, wherein said oxygen enrichment is controlled so as to maintain the carbon monoxide concentration in the exhaust gas stream at a
20 predetermined level.
4. A method as claimed in any of claims 1 to 3, wherein said oxygen enrichment is controlled manually or electronically.
25
5. A method as claimed in any of claims 1 to 4, wherein the engine is a high speed compression ignition engine.
- 30 6. A method as claimed in any of claims 1 to 4, wherein the engine is a relatively slow-speed, wide-bore compression ignition engine.
- 35 7. A method as claimed in any of claims 1 to 6, wherein said atmosphere is enriched with oxygen to between 4 and 6% above normal (25% oxygen, 75% nitrogen and 27% oxygen, 73% nitrogen).

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8. A method as claimed in any of claims 1 to 7,
wherein said atmosphere is enriched with oxygen to 5%
above normal (26% oxygen, 74% nitrogen).
- 5 9. A method as claimed in any of claims 1 to 6,
wherein said atmosphere is enriched with oxygen to above
6% above normal (27% oxygen, 73% nitrogen).
- 10 10. A method as claimed in any of claims 1 to 9,
wherein said liquid pyrolysis oil is centrifuged prior
to combustion.
- 15 11. A method as claimed in any of claims 1 to 9,
wherein said liquid pyrolysis oil is filtered prior to
combustion.
- 20 12. A method as claimed in any of claims 1 to 11,
wherein nitrogen oxides in the exhaust gas are reduced
by means of catalytic reduction with ammonia.
- 25 13. A method as claimed in any of claims 1 to 12,
wherein power from the engine is used to generate
electricity by coupling the engine to an electrical
generator.
- 30 14. A method as claimed in any of claims 1 to 13,
wherein hot exhaust gases are used to raise steam in a
steam boiler.
- 35 15. A method as claimed in claim 14, wherein steam from
the boiler drives a steam turbine, which in turn drives
an electrical generator.
16. A method as claimed in any of claims 1 to 15,
wherein heat taken from the engine, is used in a process
for the manufacture of pyrolysis oil.

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17. A method as claimed in any of claims 1 to 16,
wherein a gas separator provides oxygen or oxygen
enriched air for said atmosphere and also residual
nitrogen or nitrogen rich air, the nitrogen or nitrogen
5 rich air being used to provide an inert atmosphere in a
pyrolysis oil manufacturing process.

18. A combustion system comprising a compression
ignition engine, a means for supplying an enriched
10 oxygen atmosphere to a combustion chamber of said
engine, a means to supply liquid pyrolysis fuel to said
combustion chamber and a supply of liquid pyrolysis fuel
being derived from biomass material, wherein there is
provided a means for analysing exhaust gases emitted
15 from said engine and a means for controlling the level
of oxygen enrichment in dependence on the analysis of
said exhaust gases.

19. A system as claimed in claim 18, wherein the engine
20 is coupled to a generator for electrical power
generation.

20. A system as claimed in claim 18 or 19, further
comprising a gas separation system for producing oxygen
25 or oxygen enriched air and nitrogen or nitrogen enriched
air; and a pyrolysis oil production plant; the oxygen or
oxygen enriched air produced by the gas separation
system being supplied to said engine and the nitrogen or
nitrogen enriched air being supplied to the pyrolysis
30 oil production plant.

21. A system as claimed in claim 20, wherein waste heat
from the engine is used in the pyrolysis oil production
plant.

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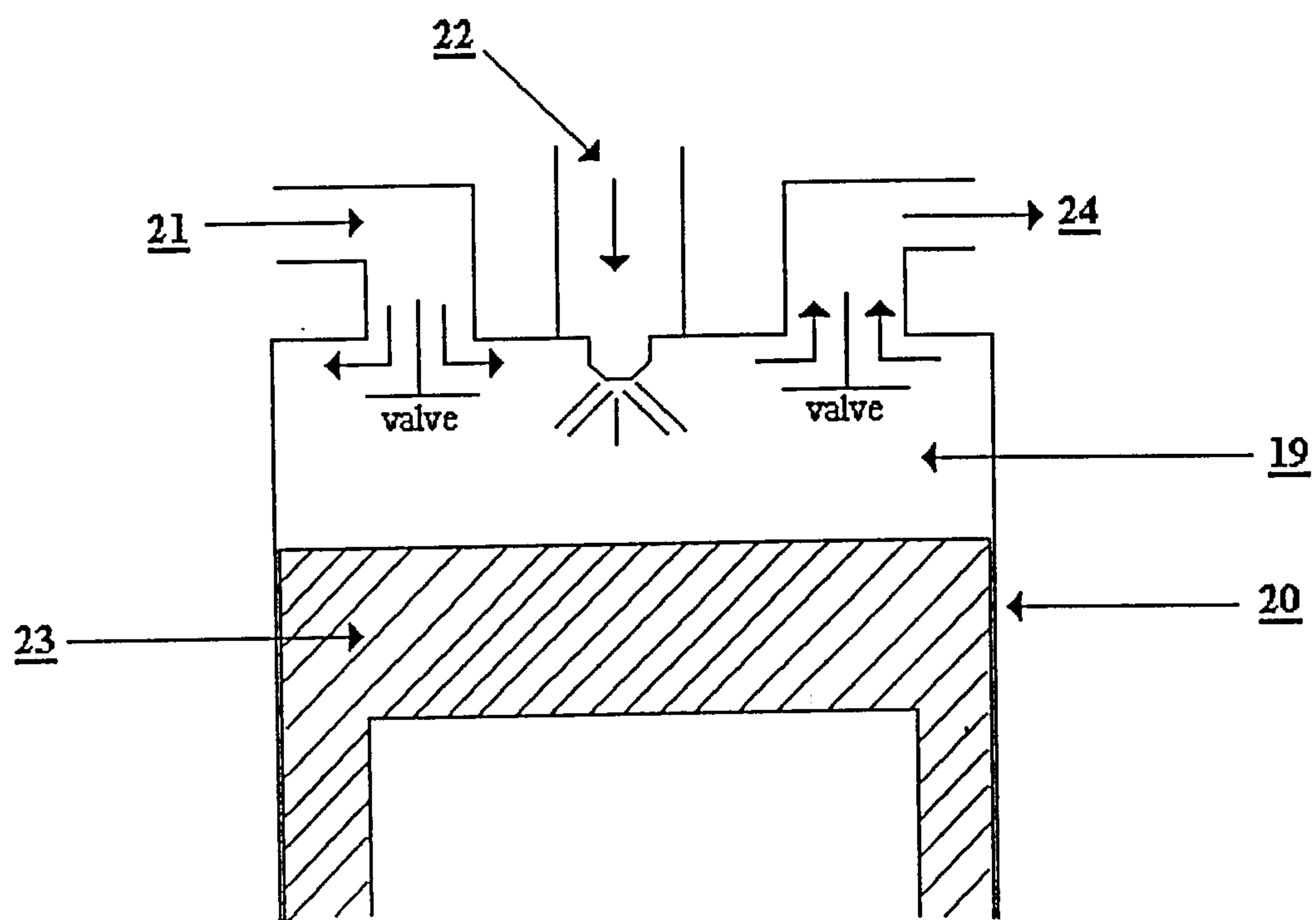
Figure 1Schematic Illustration of a Diesel Engine Cylinder Head

Figure 2
Pyrolysis Oil Combustion & Power Generation System

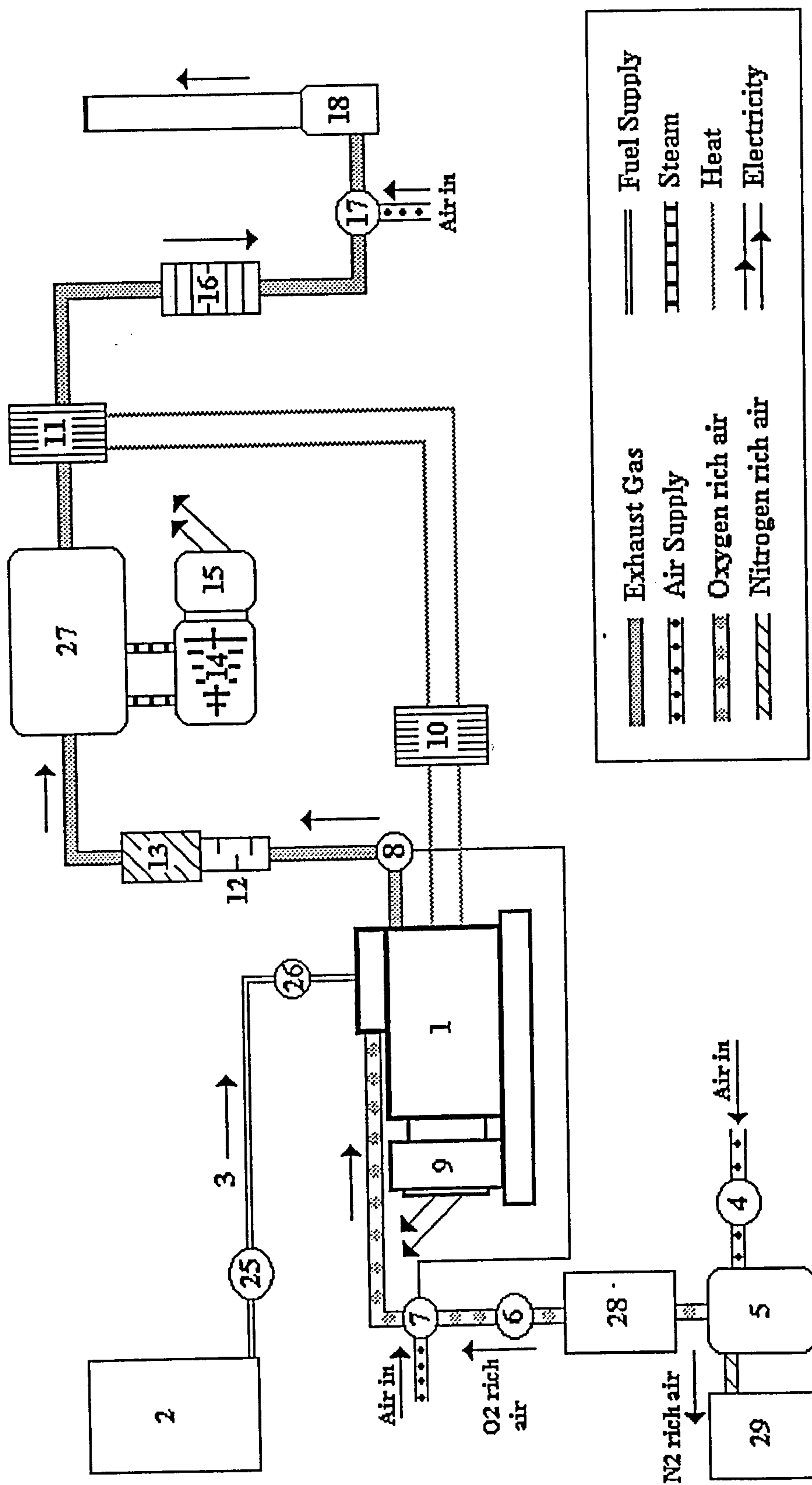
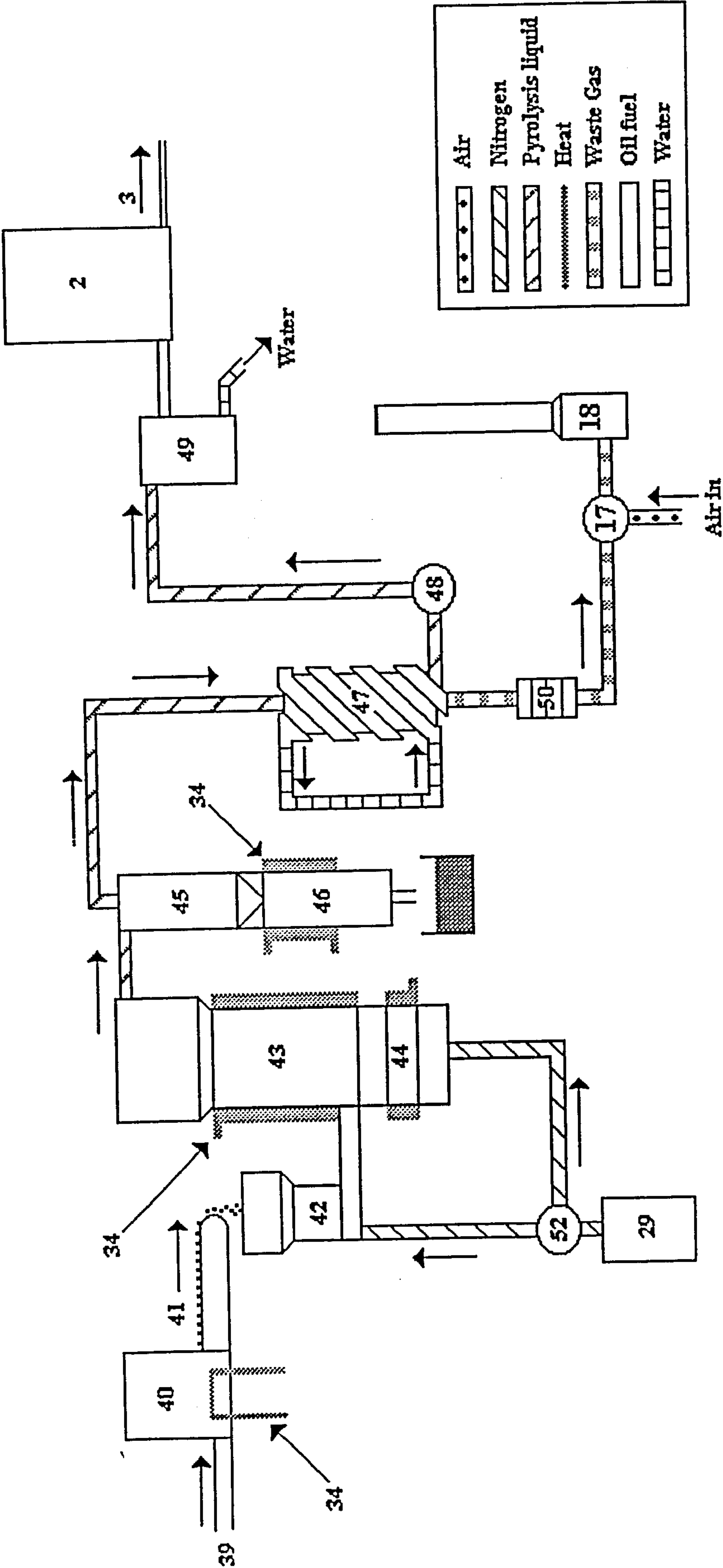
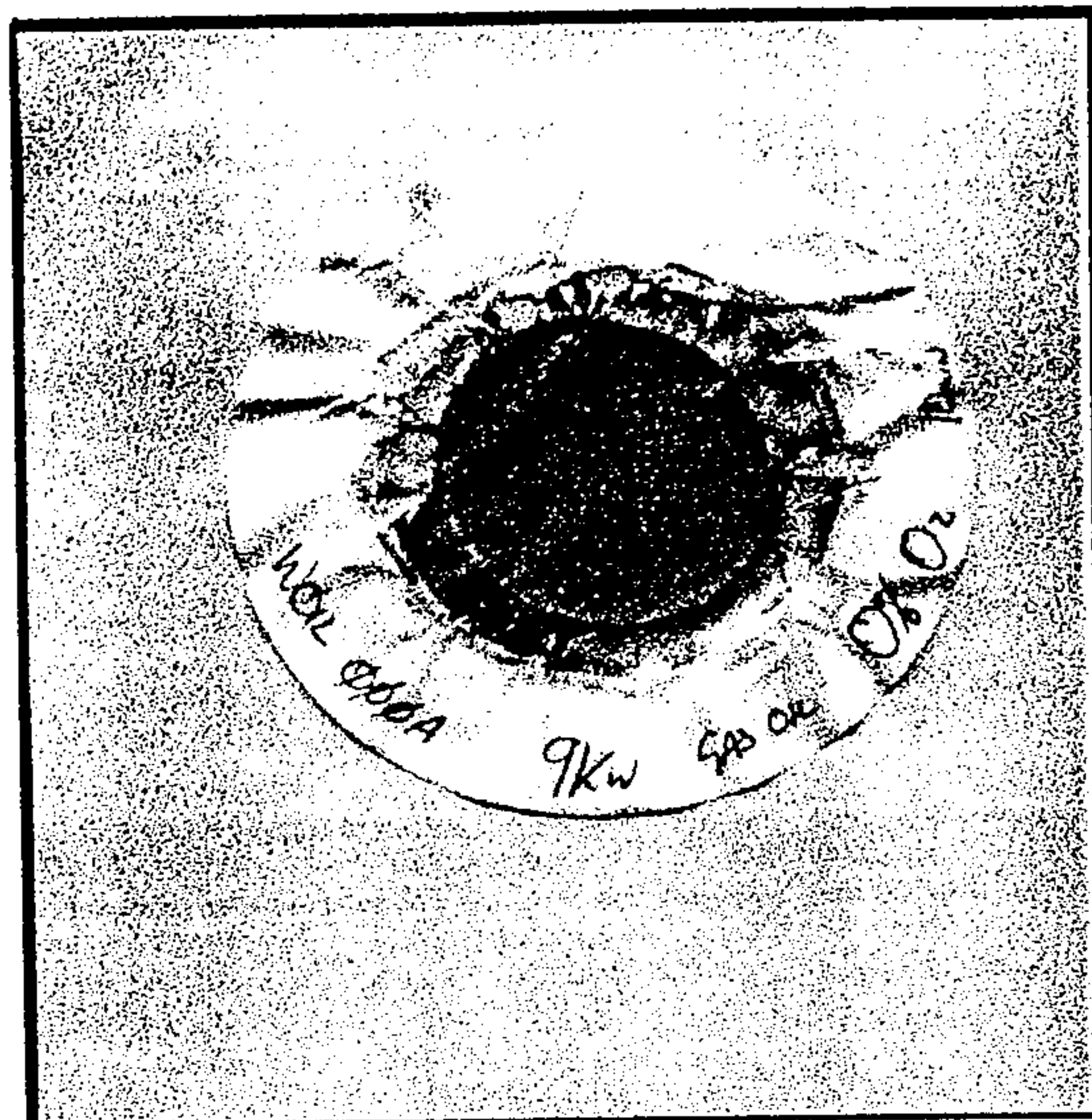


Figure 3

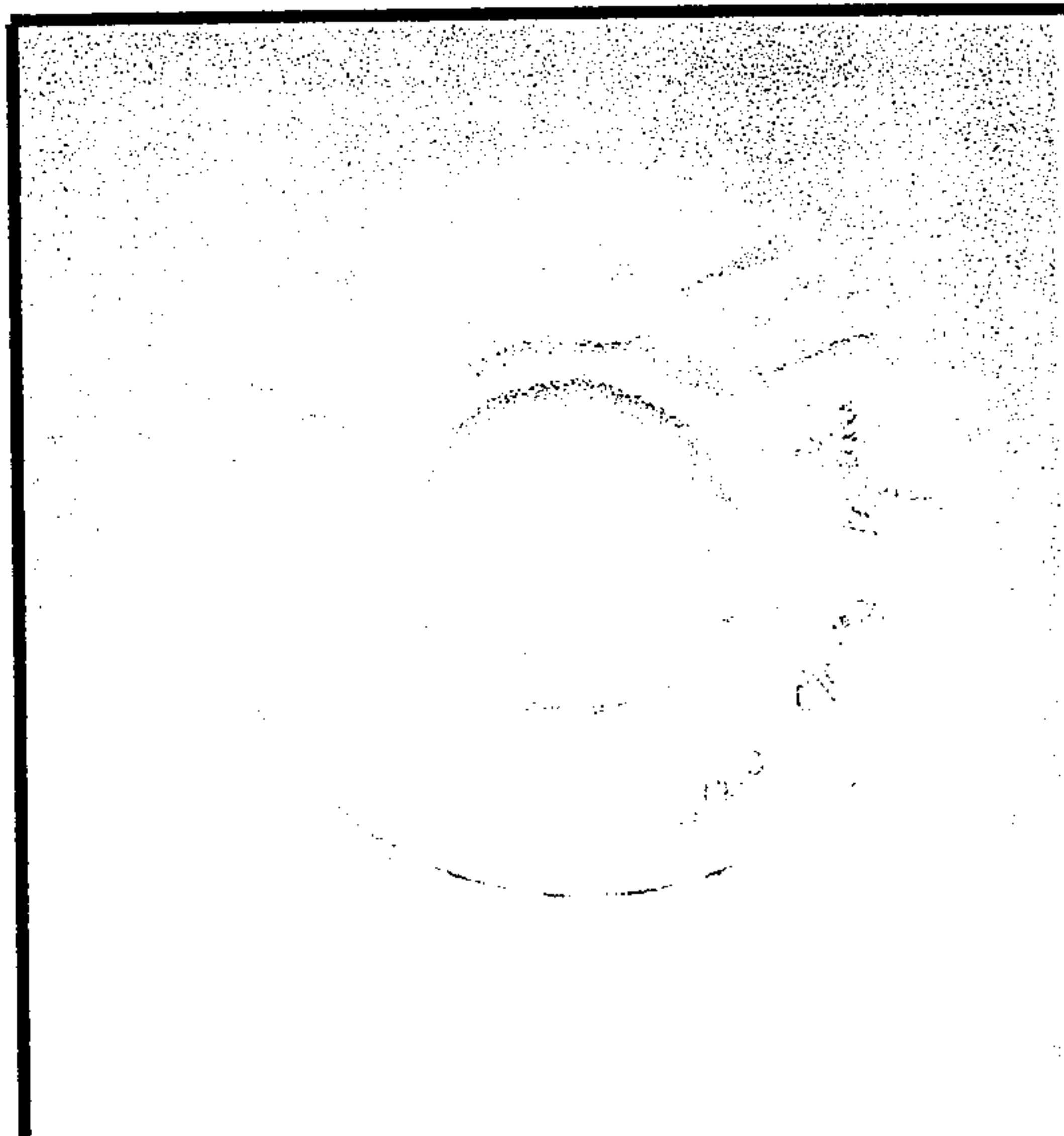
Pyrolysis Oil Manufacturing Process



4/4



Diesel oil, 21% oxygen, 9-kWe power



Pyrolysis oil, 26% oxygen, 8.5-kWe power

Figure 4

Smoke Density Filter Papers
SUBSTITUTE SHEET (RULE 26)

Pyrolysis Oil Combustion & Power Generation System

