Title: PRODUCTION OF HYDROCARBON FUELS FROM PLASTICS

Abstract: Disclosed herein is a kiln (100) for use in the production of hydrocarbon fuels from plastics. The kiln (100) comprises a scrubber (200) in fluid communication with a reaction chamber (130), the scrubber (200) being configured to condense hydrocarbons in the reaction chamber gas product stream (501) above a predetermined upper hydrocarbon range for returning to the reaction chamber (130) for further heating in the absence of oxygen. Also disclosed herein is a method of converting waste plastics to a commercially-useful form by way of diesel or the like. The method comprises treating a crude fuel produced from plastics in a pyrolytic process with a first extraction step comprising counterflow liquid-liquid extraction, and a second extraction step comprising counterflow extraction of solvents from the first extraction step.
"Production of hydrocarbon fuels from plastics"

Cross Reference to Related Applications

[0001] This patent application claims the benefit of the following Australian Provisional Patent Applications: AU2015904828, filed on 24 November 2015 and entitled KILN FOR USE IN THE PRODUCTION OF HYDROCARBON FUELS FROM PLASTICS; AU2016901654, filed on 5 May 2016 and entitled PLASTICS-DERIVED FUELS AND METHODS OF MAKING SAME; and AU2016902869, filed on 21 July 2016 and entitled PLASTICS-DERIVED FUELS AND METHODS OF MAKING SAME II, the disclosures of which are hereby incorporated by reference in their entirety.

Technical Field

[0002] The present disclosure relates generally to the production of hydrocarbon fuels from waste plastics materials.

Background

[0003] Plastics is a material typically formed of long chain organic polymers. As a result of the relatively low cost of production and ease of manufacture, plastics materials are used in a wide variety of products around the world, including a large number of disposable products such as packaging. As consumption of disposable products formed of plastics materials increases, the associated waste plastics material also increases, leading to environmental concerns due to the long life of the plastics materials if sent to landfill. Other issues associated with the dumping of waste plastics include soil contamination and infertility.

[0004] Plastics recycling is the process of recovering scrap or waste plastics and reprocessing the material into useful products. However, unlike metal recycling, the recycling of plastics materials can be challenging due to low economic returns.
Recycling of plastics can face further difficulties as a result of the chemical nature of the long chain organic polymers which can make them difficult to process. Furthermore, waste plastics materials often need sorting into the various plastic resin types, e.g. polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), for separate recycling treatments.

[0005] As plastics are formed of long chain organic polymers containing hydrogen and carbon, processes have been developed for the conversion of the long chain polymer into shorter length hydrocarbon fuel products such as petrol or diesel. These processes typically involve pyrolysis of the plastics material to reduce the long-chain polymers to polymers of smaller chain length.

[0006] Current techniques for processing plastics materials into hydrocarbon fuel products often result in the production of wax and tar type products that can foul equipment and piping used in the process. In addition, the presence of particulate materials introduced to the system or formed in the course of the reaction can result in the formation of a low purity, difficult to handle sludge-like products when condensed. Furthermore, hydrocarbons condensed directly after the pyrolysis reaction are generally required to be re-heated in order to then separate out the desired hydrocarbons.

[0007] An alternative to landfill disposal of plastics is incineration. However, this has posed problems such as damage to the furnace and the emission of harmful gases and an offensive odour. Society's ever-increasing environmental consciousness has deemed incineration a largely unpopular and unsustainable method of disposing of waste plastics.

[0008] In the United States, the Package Recycle Law which prescribes the duty of recovering and reusing plastics was enacted in 1995. In view of these circumstances, various attempts have recently been made to reuse plastics waste as resources. However, two decades after the enactment of this law, only 8% of all plastics waste is actually recycled. Clearly, there are environmental drivers toward increasing the rate
of recycling. However, logistical and abiding societal factors still dictate that the vast majority of plastics waste is dumped, or even worse, incinerated.

[0009] A further consideration is that the mineral cost of supplying the world with its ever-increasing demand for plastics accounts for approximately 7% of the global crude oil consumption on an annual basis. In brief, it costs oil to make plastics - and unless that oil is recoverable once the plastics has served its commercial purpose, our global mineral debt only serves to increase.

[0010] The Japanese inventor Akinori Ito popularised the idea of converting waste plastics back into fuel oil through plastic pyrolysis. Pyrolysis is a thermochemical decomposition of organic material, such as plastics, at elevated temperature in the absence of oxygen. It involves the simultaneous change of chemical composition and physical phase, and is irreversible. Pyrolysis typically occurs at temperatures in the range of 400-900 °C, at small excess pressure. This process, for example, is widely used in petroleum refinery for obtaining low molecular monomers from naphtha, and it can used for waste plastics processing with fuels production as an alternative of its incineration or landfilling.

[0011] In this process, the long polymer molecules of plastics materials are broken down into shorter chains of hydrocarbons with the help of heat and pressure. Essentially, the process mimics nature in which organic materials are broken down into oil over thousands or even millions of years. The pyrolysis process achieves this with intense heat in a closed, anaerobic system over a short period. A catalyst can be used to lower the temperature and increase the yield. Other substances which can be pyrolysed are biomass, waste tires, lubricating oils, coal and petroleum residues; waste tire pyrolysis being the most popular and the most profitable of them all.

[0012] The basic process of pyrolysis proceeds as follows: (1) A shredding step in which the waste material must be segregated and, if possible, cleaned. Then it is shredded to speed up the reaction and to ensure that the reaction is complete. (2) An anaerobic heating step in which the shredded material is heated in a controlled manner
in an oxygen-free reactor. One of the most crucial factors in this operation is maintaining the correct temperature (-430 °C for plastics) and the rate of heating, as they define the quality and the quantity of the final product. (3) A condensation step in which the gas that comes out from the reactor is condensed by passing it through a condensation tube or by directly bubbling it in water. (4) A distillation step in which the resultant mixture of oil can be used as furnace oil but is insufficiently pure for engines. In order to be able to use it as engine fuel, the desired products need to be extracted and purified from the mixture through fractional distillation, or some other purification means.

[0013] Some of the benefits of pyrolysis are that the process does not generate harmful pollutants and that the by-products can be used as fuel for running the plant. In the case of plastics, some of the valuable fuels and solvents that can be extracted through waste plastic pyrolysis are gasoline, kerosene, diesel, benzene, LPG, toluene and xylene. Moreover, the pyrolytic process is relatively efficient in that one kilogram of waste can yield up to one litre of fuel. By direct comparison, incineration of the same quantity of plastics would produce three kilograms of carbon dioxide.

[0014] Anhydrous pyrolysis can be used to produce liquid fuel similar to diesel from plastic waste, with a higher cetane value and lower sulfur content than traditional diesel. Using pyrolysis to extract fuel from end-of-life plastics is a second-best option after recycling, is environmentally preferable to landfill, and can help reduce dependency on foreign fossil fuels and geo-extraction. Moreover, plastics-derived diesel fuel is obtainable in a form pure enough for commercial sale and consumption. On the other hand, such technologies are still in their infancy - and it is a known goal of the art to find ever more efficient means of obtaining fuels from waste plastics.

[0015] European patent application 0 620 264 A2 discloses a process for making a lube oil from waste plastics. The process utilises a cracking process in a fluidised bed of inert solids and fluidised with, for instance, nitrogen. The product of the cracking is hydrotreated over an alumina catalyst or other refractory metal oxide support containing a metal component, and then optionally catalytically isomerised. The overall
yield, however, is lower than desired. The isomerisation catalysts taught partially cause this result. There is no teaching of using better isomerisation catalysts. Also, EP 0 620 264 A2 does not teach a process of producing a high yield of heavy lube oils.

[0016] Many methods for preparing low-boiling hydrocarbons from waste plastics and high-boiling hydrocarbons are known. US 4,851,601 describes a reaction of pyrolysis in a reactor kettle (vertical or horizontal), wherein the outside wall of the kettle is heated at a high temperature while the materials therein are heated indirectly. In this method, the outside wall is apt to be deformed when the reactor is heated directly at a high temperature. The materials are readily sintered on the inside wall because of local over-heating so that the conversion yield of the reaction and the life of the reactor are greatly decreased. In addition, the coefficient of the reactor's heat transfer is relatively low, it is difficult to drain the reaction residues, and the catalytic reaction in the fixed bed needs a separate heat supply. These are the common drawbacks of the reactor kettle in the prior art.

[0017] A spiral reactor utilised in some special fields is similar to the above. Heat is indirectly transferred when it works. The outside wall of the reactor is heated directly at a high temperature, making the materials in the reactor indirectly heated. Therefore, the heat transfer coefficient is not satisfactory.

[0018] It will be appreciated also that the desirability of working a method of extracting diesel from plastics may be of limited appeal in cases where the method itself gives rise to significant quantities of contaminated waste solvents. Accordingly, it would also be advantageous to provide means for regenerating or recycling spent solvents used in the extraction method.

[0019] Thus, in a preferred form, one or more embodiments of the presently disclosed concepts are able to operate as an effective standalone continuous (or indeed batch, if desired) process, at once providing for the extraction of diesel from waste plastics and the recycling of the solvents used to perform the extraction.
Although the general principles disclosed herein are described hereinafter with reference to specific examples, it will be appreciated by those skilled in the art that they may be embodied in many other forms.

Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present disclosure as it existed before the priority date of each claim of this application.

Summary

Throughout this specification, the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

In a first aspect, there is provided a kiln for use in the production of hydrocarbon fuels from plastics, the kiln comprising:

- a reaction chamber;
- a feed inlet for feeding plastic feed material into the reaction chamber;
- a heater for heating the reaction chamber; and
- a scrubber in direct fluid communication with the reaction chamber;

wherein the kiln is configured such that plastic feed material in the reaction chamber is heated in an absence of oxygen thereby to decompose at least a portion of the plastic feed material into a reaction chamber gas product stream comprising hydrocarbons suitable for use as fuel, and

wherein the scrubber is configured to remove hydrocarbons in the reaction chamber gas product stream above a predetermined upper hydrocarbon range for returning to the reaction chamber for further heating in the absence of oxygen.
[0024] The kiln may be configured such that the temperature of the reaction chamber gas product stream exiting the reaction chamber does not drop substantially before entering the scrubber.

[0025] The scrubber may be configured such that a scrubber gas stream exiting the scrubber is at a temperature of less than 350°C.

[0026] The kiln may be a cylindrical horizontal kiln comprising a cylindrical outer shell and the reaction chamber may comprise an inner tube positioned concentrically in the cylindrical outer shell.

[0027] The heater for heating the reaction chamber may comprise a heat flow medium flowing in an annulus defined between the central inner tube and outer shell, such that the heat source medium heats an outer surface of the inner tube.

[0028] The outer surface of the inner tube may comprise a plurality of vortex generators for increasing heat transfer efficiency from the heat source medium to the reaction chamber.

[0029] The kiln may further comprise a stirrer for stirring the plastic feed material in the reaction chamber. Additionally, the kiln may further comprise a catalyst in the reaction chamber for pushing the reaction towards hydrocarbons of desirable chain length and/or desired aromatic hydrocarbons.

[0030] The kiln may further comprise a waste particulate outlet for removing waste particulate material from the reaction chamber.

[0031] In a second aspect, there is provided a system for the production of hydrocarbon fuels from plastics, the system comprising a kiln according to the first aspect.

[0032] The system may further comprise at least one hydrocarbon recovery device for recovering hydrocarbons within a predetermined hydrocarbon range. The at least one
hydrocarbon recovery device may be one or more of: a fractionation column configured to condense diesel range hydrocarbons from a hydrocarbon gas stream; a condenser configured to condense petrol range hydrocarbons from a hydrocarbon gas stream; and/or a compression device configured to condense liquid petroleum gas (LPG) range hydrocarbons from a hydrocarbon gas stream. It will be appreciated that the selection of equipment for condensing hydrocarbon gases leaving the kiln will depend on the desired final product.

[0033] The fractionation column may be in fluid communication with a gas outlet of the scrubber. The fractionation column may be further configured to divert at least a portion of condensed diesel to the scrubber for use as a scrubbing liquid.

[0034] A vacuum tower may be provided for removing water from diesel range hydrocarbons condensed by the fractionation column.

[0035] The condenser may be in fluid communication with a gas outlet of the fractionation column.

[0036] The compression device may be in fluid communication a gas outlet of the condenser.

[0037] In a third aspect, there is provided an assembly for use in the production of hydrocarbon fuels from plastics, the assembly comprising:

- a kiln comprising:
  - a reaction chamber;
  - a feed inlet for feeding plastics feed material into the reaction chamber;
  and
  - a heater for heating the reaction chamber,

wherein the kiln is configured such that plastics feed material in the reaction chamber is heated in an absence of oxygen thereby to decompose at least a portion of the plastics feed material into a reaction chamber gas product stream comprising hydrocarbons suitable for use as fuel,
a scrubber in fluid communication with the reaction chamber, wherein the scrubber is configured to remove hydrocarbons in the reaction chamber gas product stream above a predetermined upper hydrocarbon range and return the removed hydrocarbons to the reaction chamber for further heating in the absence of oxygen; and a hydrocarbon recovery device in fluid communication with the scrubber for receiving a remainder of the reaction chamber gas product stream, the hydrocarbon recovery device being configured to remove hydrocarbons within a predetermined hydrocarbon range from said remainder.

[0038] In a fourth aspect there is provided a method for deriving fuel from plastics, the method comprising subjecting a quantity of plastics to a pyrolytic process, thereby to convert at least a portion of the plastics to a crude fuel; and extracting the fuel in a directly usable form by way of:

a first extraction step comprising counterflow liquid-liquid extraction using one or more extraction solvents to extract one or more impurities from the crude fuel;

a second extraction step comprising counterflow extraction of the resultant contaminated one or more extraction solvents from the first extraction step; and

optionally, an extraction solvent purification step wherein the contaminated one or more extraction solvents are purified to enable their re-use in a subsequent one or more of the extraction steps.

[0039] In an embodiment, the second extraction step comprises using a highly polar liquid such as water, alcohol, or the like, or mixtures thereof to increase the polarity of the contaminated extraction solvent, in turn causing the extraction solvent to reject the extract; and then distilling the one or more polar compounds from the extraction solvent.

[0040] The method defined according to the fourth aspect may be substantially as depicted with respect to Figures 2 and 3 of the accompanying drawings.

[0041] In a fifth aspect there is provided a method for deriving fuel from plastics, the method comprising subjecting a quantity of plastics to a pyrolytic process, thereby to
convert at least a portion of the plastics to a crude fuel; and extracting the fuel in a
directly usable form by way of:

- a first extraction step comprising counterflow liquid-liquid extraction using
  one or more extraction solvents to extract one or more impurities from the crude fuel;
- a second extraction step comprising counterflow extraction of the resultant
  contaminated one or more extraction solvents from the first extraction step.

[0042] In an embodiment, the second extraction step comprises using a light end non-
polar solvent such as heptanes, hexanes, or the like, or mixtures thereof, that extract
aromatics and compounds of similar polarity from the extraction solvent; and then
distilling the light end solvent from the extraction solvent.

[0043] The method defined according to the fifth aspect may be substantially as
depicted with respect to Figures 4 and 5 of the accompanying drawings.

[0044] In one or more embodiment, the extraction solvent is N-methyl-2-pyrrolidone,
or similar dipolar aprotic solvents such as dimethylformamide, dimethyl sulfoxide or
the like. However, it will be appreciated that any solvent having appropriate physical
and polar characteristics may be used.

[0045] In one or more embodiment, the extraction solvent purification step is
performed. Performing the extraction solvent purification step in a substantially
continuous manner provides for substantially continuous operation of the first and/or
second extraction steps.

[0046] In one or more embodiment, in the counterflow extraction, the extraction
solvent enters the top of a packed column and the crude fuel enters the bottom of the
packed column. Alternatively, the extraction solvent enters the bottom of a packed
column and the crude fuel enters the top of the packed column.

[0047] In one or more embodiment, the extraction solvent extracts impurities
resulting in contaminated extraction solvent exiting the bottom of the packed column
and purified fuel exiting the top of the packed column. Alternatively, the contaminated extraction solvent may exit the top of a packed column and the purified fuel may exit the bottom of the packed column.

[0048] In one or more embodiment, the contaminated extraction solvent is mixed with water, alcohol, or the like, or mixtures thereof which causes the non-polar compounds such as aromatics to come out of solution. Suitable solvents would be anything having a polarity in the range of alcohols to water.

[0049] In one or more embodiment, the impurity compounds flow off the extraction solvent which is contaminated with the water.

[0050] In one or more embodiment, the water is distilled out of the extraction solvent using conventional rising film evaporators. This distillation may or may not occur under vacuum and may or may not employ a series of multi-effect evaporators to reduce distillation thermal energy requirements. Distillation may be effected by conventional techniques.

[0051] In one or more embodiment, both the water and the extraction solvent are recycled. This recycling has clear environmental and economic advantages, as well as liberating some residual crude pyrolysis product which can be disposed of, but is otherwise employed as a marine diesel fuel or boiler fuel.

[0052] In one or more embodiment, in the counterflow extraction, the extraction solvent enters the top of a packed column and the crude fuel enters the bottom of the packed column. Alternatively, in the counterflow extraction, the extraction solvent may enter the bottom of a packed column and the crude fuel may enter the top of the packed column.

[0053] In one or more embodiment, the extraction solvent extracts impurities resulting in contaminated extraction solvent exiting the bottom of the packed column and purified fuel exiting the top of the packed column. Alternatively, the contaminated
extraction solvent may exit the top of the packed column and purified fuel may exit the bottom of the packed column.

[0054] In one or more embodiment, the contaminated extraction solvent is pumped to another counterflow extraction set-up which uses the light end non-polar solvent to extract aromatics, sulfur compounds and similar from the extraction solvent.

[0055] In one or more embodiment, the light end non-polar solvent is distilled and recycled leaving concentrated aromatics, sulfur compounds and similar and clean extraction solvent.

[0056] In one or more embodiment, both the light end non-polar solvent and the extraction solvent are recycled.

[0057] In one or more embodiment, the fuel is a diesel blend.

[0058] In one or more embodiment, the plastics are waste plastics otherwise destined for recycling, landfill, or incineration.

[0059] In one or more embodiment, the pyrolytic process by which the plastics are converted to the crude fuel takes place at about 450 °C, over a period of about 30 minutes. However, it will be appreciated that any temperature and period over which pyrolysis can be effected is applicable to the present invention.

[0060] In one or more embodiment, the first and second extractions steps take place at substantially ambient pressure, at about 80 °C and over a counterflow extraction period of less than about 20 minutes. However, it will be appreciated that any pressure, temperature and period over which extraction can be effected is applicable to the presently disclosed principles.

[0061] In one or more embodiment, the method is adapted to be scalable to a commercial scale of greater than 1000 tons fuel per day. In one or more embodiment, the method is also scalable to a pilot plant scale.
In one or more embodiment, the method gives rise to yields of about 70% w/w diesel and about 15% w/w gasoline per unit plastics. However, to an appreciable extent, the recovery of fuel from the waste plastics is dictated firstly by the composition of the waste plastics and by the conditions (temperature, pressure, period) under which the pyrolysis step is effected.

In one or more embodiment, the extraction solvent is N-methyl-2-pyrrolidone (NMP; CAS 872-50-4).

In one or more embodiment, the fuel is directly transferrable to commercial at-the-pump sale and meets the Australian Diesel Fuel Quality Standard (Fuel Standard (Automotive Diesel) Determination 2001, as amended, made under section 21 of the Fuel Quality Standards Act 2000).

In one or more embodiment, the method is adaptable to be financially profitable down to about AU$16/bbl oil. However, it will be appreciated that as the method is refined and made more efficient, the profitability on a per-barrel basis will increase accordingly.

In one or more embodiment, the waste product obtained following recycling of the extraction solvent is adaptable for use as a boiler fuel or marine diesel oil, or can be stored.

In one or more embodiment, the extraction solvent purification step comprises the contaminated one or more extraction solvents entering a rising film evaporator at between about -80 and -90 kPa.

The method of the fourth and/or fifth aspects may be performed on crude fuel output from the kiln, system or assembly of the first, second or third aspects.

In a sixth aspect there is provided a diesel blend fuel when obtained by a method as defined according to the fourth or fifth aspects. In one or more embodiment,
the fuel is directly transferrable to commercial at-the-pump sale and meets the Australian Diesel Fuel Quality Standard (Fuel Standard (Automotive Diesel) Determination 2001, as amended, made under section 21 of the Fuel Quality Standards Act 2000), as well as ASTM D975-15c and EN590 standards.

[0070] In a seventh aspect there is provided recycled one or more extraction solvents when obtained by a method as defined according to the fourth or fifth aspects.

[0071] In one or more embodiment, the recycled one or more extraction solvents are found to be of sufficient purity to allow their re-use in a further one or more iterations of the process disclosed herein.

**Brief Description of Drawings**

[0072] Embodiments of the presently disclosed kiln will now be described by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of a system for the conversion of plastics to hydrocarbon fuels;

Figure 2 is a schematic diagram of an embodiment of a method for deriving fuel from plastics;

Figure 3 represents the same process as that depicted in Figure 2, with an additional NMP solvent purification step being signified;

Figure 4 is a schematic diagram of a further embodiment of a method for deriving fuel from plastics;

Figure 5 represents the same process as that depicted in Figure 4, with an additional NMP solvent purification step being signified;

Figure 6 is a schematic representation of a back-end NMP solvent purification process as defined in certain embodiments of the presently disclosed principles;

Figure 7 is a photograph of a crude plastic-derived diesel following pyrolysis of crude waste plastics;

Figure 8 is a photograph of an extraction step; and

Figure 9 is a final purified diesel product following the NMP extraction steps.
Description of Embodiments

[0073] Referring to Figure 1, there is provided a system 10 for the conversion of plastics to hydrocarbon fuels such as diesel, petrol and liquid petroleum gas (LPG). The classification of hydrocarbon fuels depends primarily on the range of chain lengths of the hydrocarbons in the fuel mix, for example diesel hydrocarbons typically range from C10 to C25, petrol hydrocarbons from C4 to C12, and liquid petroleum gas (LPG) typically comprises a mixture of propane (C₃H₈) and butane (C₄H₁₀).

[0074] The system 10 comprises a plastic feed material 500 being fed to a kiln 100. The plastic feed material 500 may be any plastic material formed of long-chain organic polymers, for example waste plastic materials such as plastic packaging or automotive tyres. The plastic feed material 500 may undergo pre-processing prior to introduction into the kiln 100, for example shredding or chopping to improve handling and surface area of the plastic feed material, or drying to minimise the amount of water introduced to the system. The plastic feed material 500 is fed to a feed inlet 110 of the kiln 100 by a feeder 120 in a manner so as to reduce heat and gas loss from the kiln. For example, the plastic feed material 500 may be fed to the feed inlet 110 using a double slide-gate feeder or a plug screw feeder. The feeder 120 also allows for the control of the rate of flow of the plastic feed material 500 into the kiln 100.

[0075] The kiln 100 is a cylindrical horizontal kiln comprising a reaction chamber 130 in the form of a central inner tube through which the plastic feed material 500 flows, and a heater comprising a heat source 800 for heating the reaction chamber. The reaction chamber 130 comprises a plurality of stirrers 140 mounted at right angles to a horizontal rotating shaft 150 for stirring the plastic feed material in the reaction chamber 130. In addition to improving heat transfer to the plastic feed material 500, the rotating stirrers 140 also assist in the removal of waste particulate material from the reaction chamber 130 and prevention of waxy build-up on the reaction chamber 130 inner walls.
[0076] The heat source 800 may be any suitable heat source for heating the reaction chamber 130 and its contents, such as a heat source medium which flows through an annular region between a concentric outer tube 160 and the reaction chamber 130, the heat source medium 800 transferring heat through an outer wall of the reaction chamber 130. The heat source medium 800 may be sourced from other process equipment used in or in conjunction with the system, for example the heat source medium 800 may be combustion gases from a cyclone combustor 170 used to treat waste products from the system, such as non-condensable gases and char. The outer wall of the reaction chamber 130 further comprises a plurality of vortex generators (not shown) to increase heat transfer efficiency between the heat source medium 800 and the reaction chamber 130.

[0077] In the reaction chamber 130, the plastic feed material 500 is heated in the absence of oxygen such that at least a portion of the plastic feed material 500 first melts, then decomposes into a reaction chamber gas product stream 501 comprising hydrocarbons ranging from hydrogen to heavy wax, with the majority of the gases being in the liquid fuel range. A catalyst such as activated bauxite may further be provided in the reaction chamber 130 for pushing the reaction towards hydrocarbons of desirable chain length and/or desired aromatic hydrocarbons. Waste particulate material such as char, dust and ash may also be formed in the reaction chamber 130 as the plastic feed material 500 is heated or may be introduced with the plastic feed material 500. The kiln is provided with a waste particulate outlet 180 in fluid communication with the reaction chamber 130 for removing at least a portion of the waste particulate material formed in the reaction chamber.

[0078] The kiln 100 further comprises a product outlet 190 and a scrubber 200 at the product outlet 190. The reaction chamber gas product stream 501 exits the reaction chamber 130 through the product outlet 190 and flows through the scrubber 200. It will be appreciated that the exiting reaction chamber gas product stream 501 may also contain a portion of the above described waste particulate material. The scrubber 200 is preferably a packed scrubbing column comprising plate or ring-type packing. In the scrubber 200, the reaction chamber gas product stream 501 is brought into contact with
a hydrocarbon scrubbing liquid 502 for condensing heavier, higher boiling point,
hydrocarbons present in the reaction chamber gas product stream 501, wherein the
condensed hydrocarbons and the scrubbing liquid flow back into the reaction chamber
to undergo further reaction. The remaining, lighter weight, hydrocarbons exit the
scrubber as a scrubber gas product stream 503. The scrubbing liquid 502 also acts to
wash the reaction chamber gas product stream 501 of waste particulate material which
flows back to the reaction chamber 130 with the scrubbing liquid 502 and the
condensed heavier hydrocarbons.

[0079] It will be appreciated that the scrubber 200 is in direct fluid communication
with the reaction chamber 130 such that the reaction chamber gas product stream 501
exiting the reaction chamber 130 flows directly to the scrubber 200. This minimises
any cooling of the reaction chamber gas product stream 501 prior to entering the
scrubber 200 which may lead to the formation of solid waxy residue being deposited in
conduits connecting the reaction chamber 130 and the scrubber 200. The above
described relative positioning of the reaction chamber 130 and the scrubber 200 further
avoids the need to reheat the product from the reaction chamber 130 in order to
separate out the desired hydrocarbons.

[0080] The system 10 further comprises at least one hydrocarbon recovery device for
recovering hydrocarbons within a predetermined hydrocarbon range. In the system 10
of Figure 1, there is provided a number of hydrocarbon recovery devices, discussed in
more detail below, for recovering various components of the hydrocarbon gas product
stream produced in the kiln, including a fractionation column 210 configured to
condense diesel range hydrocarbons, a condenser 240 configured to condense petrol
range hydrocarbons, and a gas compression and cooling device configured to condense
liquid petroleum gas (LPG) range hydrocarbons.

[0081] The scrubber gas product stream 503 then enters a fractionation column 210
where the scrubber gas product stream 503 is brought into contact with a hydrocarbon
reflux 504 selected for causing diesel range hydrocarbons 506 to condense and flow to
out bottom of the fractionation column 210 while the gasoline and lighter hydrocarbons
exit the top of the fractionation column 210 as a fractionation gas product stream 505. A portion of the diesel range hydrocarbons 506 exiting the fractionation column 210 is used as the scrubbing liquid 502 for scrubbing the reaction chamber gas product stream 501.

[0082] The remaining diesel 507 may then be treated prior to storage is a diesel storage vessel. In one example, the remaining diesel 507 is treated to remove moisture, for example by vacuum drying 220, and with the treated diesel 508 collected and stored in a diesel storage vessel 230. In another example, the diesel may undergo a solvent extraction processes, as discussed in more detail below, to extract impurities such as aromatics, sulphur compounds and similar.

[0083] It will be appreciated that the operation conditions of the kiln 100 and scrubber 200 will be dependent on the type of plastic feed material 500 to be processed and the desired hydrocarbon product to be recovered. For example, the targeted recovery of the lighter weight liquid petroleum gas (LPG) range hydrocarbons may require higher operating temperatures in the kiln than for the targeted recovery of diesel range hydrocarbons. While temperature in the kiln 100 is important, careful control of the temperature at the product outlet 190 (i.e. the scrubber inlet) and the scrubber outlet can play an important role in the composition of the final products. These temperatures can be controlled, for example, by controlling the temperature in the reaction chamber 130 and/or controlling the flow rate of the scrubbing liquid 502 into the scrubber 200. Preferably, the temperature of the scrubber gas stream 503 exiting the scrubber is maintained below 350°C such that heavy, long-chain hydrocarbons unsuitable for use as fuel, condense and flow back to the reaction chamber 130 for further treatment.

[0084] The fractionation gas product stream 505 exiting the fractionation column 210 flows through a condenser 240 configured to condense the petrol range hydrocarbons 504, 509 in the fractionation gas product stream 505. A portion of the condensed petrol range hydrocarbons exiting the condenser are used as the hydrocarbon reflux 504 for the fractionation column 210. The remaining petrol 509 is collected and stored in a petrol storage vessel 250. As described above for the diesel 507, the petrol 509 may be
treated prior to storage in petrol storage vessel. For example, the petrol 509 may undergo a solvent extraction processes, as discussed in more detail below, to extract impurities such as aromatics, sulphur compounds and similar.

[0085] Any remaining gases that were not condensed in the condenser 240, i.e. due to very low molecular weight and low boiling points, exit the condenser 240 as a condenser gas product stream 510. The condenser gas product stream 510 is fed to a gas compression and cooling device 260 configured to extract liquid petroleum gas (LPG) range hydrocarbons from the condenser gas product stream 510. The extracted LPG range hydrocarbons 511 are collected and stored in a LPG storage vessel 270.

[0086] Non-condensable gases 512 that are not recovered in the gas compression and cooling device 260 may be used in other process equipment, such as to at least partially fuel the cyclone combustor 170 as described above.

[0087] Referring now to Figure 2 of the accompanying drawings, there is provided a schematic diagram of the process represented according to the fourth aspect. This aspect defines a method for deriving fuel from plastics, the method comprising a preliminary step subjecting a quantity of plastics to a pyrolytic process (not shown), thereby to convert at least a portion of the plastics to a crude fuel, in this case, crude diesel (1). The pyrolytic process by which the plastics are converted to the crude fuel takes place at about 450 °C, over a period of about 30 minutes.

[0088] It will be appreciated that the pyrolytic process may be that described with reference to the kiln 100 above, with the crude fuel being any of the described hydrocarbon fuel streams, e.g. diesel 507, petrol 509, resulting from the operation of the kiln 100.

[0089] The process comprises a first extraction step obtaining the fuel in a directly usable form by way of: a first extraction step comprising counterflow liquid-liquid extraction in a packed column (2) using one or more extraction solvents (3), preferably in the form of N-methyl-2-pyrrolidone (NMP). The NMP serves to extract one or more
impurities from the crude fuel. The purified diesel (4) is obtained from an exit stream, either at the top, or bottom of the packed column (2).

[0090] The process then comprises a second extraction step comprising counterflow extraction of the resultant contaminated NMP from the first extraction step (5). The second extraction step comprises using water, alcohol, or the like, or mixtures thereof (6A) to increase the polarity of the contaminated extraction solvent, in turn causing the extraction solvent to reject the extract. The second counterflow step again takes place in a packed column (7) and gives rise to an exit stream of contaminants (8A) such as sulfur compounds, aromatics, etc., and an exit stream of water-contaminated NMP solvent (9).

[0091] Optionally, an extraction solvent purification step is performed, wherein the contaminated extraction solvents are purified to enable their re-use in a subsequent one or more of the extraction steps; this will be discussed further, below.

[0092] The first and second extractions steps take place at substantially ambient pressure, at about 80 °C and over a counterflow extraction period of less than about 20 minutes.

[0093] In a final step, the water-contaminated NMP solvent (9) is then distilled using a standard distillation column (10), which gives rise to recycled water (11A) and recycled NMP (12). The waste product obtained following recycling of the extraction solvent is adaptable for use as a boiler fuel or marine diesel oil.

[0094] It will be appreciated that the extraction of the purified diesel (4) takes place within the first extraction step, with the second extraction step and subsequent distillation steps serving to provide a means of recycling the NMP and water solvents.

[0095] The method is adapted to be scalable to a commercial scale of greater than 1000 tons fuel per day. However, during scale-up, the method is also scalable to a pilot plant scale.
The method gives rise to yields of about 70% w/w diesel and about 15% w/w gasoline per unit plastics. However, to an appreciable extent, the recovery of fuel from the waste plastics is dictated firstly by the composition of the waste plastics and by the conditions (temperature, pressure, period) under which the pyrolysis step is effected.


It will be appreciated that the process as depicted according to Figure 3 is substantially the same as that of Figure 2, with the additional extraction solvent purification step being performed.

Often, it is found that there is a heavy contaminant in the extraction solvent/s (NMP) that is not removed other than by one or more deliberate purification steps. It is found that the contaminant may be one or more heavy hydrocarbons with a boiling point higher than NMP. Thus the NMP can be purified by an additional simple distillation step as depicted in Figure 6 and discussed below.

For completeness, and with regard to Figure 4 of the accompanying drawings, there is provided a schematic diagram of the process represented according to the fifth aspect. In the ensuing description of the second aspect, actions or reagents equivalent with those referenced in the fourth aspect (Figures 2 and 3) have been given consistent designations, e.g., NMP (3), etc.

The fifth aspect defines a method for deriving fuel from plastics, the method comprising a preliminary step subjecting a quantity of plastics to a pyrolytic process (not shown), thereby to convert at least a portion of the plastics to a crude fuel, in this case, crude diesel (1). The pyrolytic process by which the plastics are converted to the crude fuel takes place at about 450 °C, over a period of about 30 minutes.
The process comprises a first extraction step obtaining the fuel in a directly usable form by way of: a first extraction step comprising counterflow liquid-liquid extraction in a packed column (2) using one or more extraction solvents (3), preferably in the form of N-methyl-2-pyrrolidone (NMP). The NMP serves to extract one or more impurities from the crude fuel. The purified diesel (4) is obtained from an exit stream, either at the top, or bottom of the packed column (2).

The process then comprises a second extraction step comprising counterflow extraction of the resultant contaminated NMP from the first extraction step (5). The second extraction step comprises using hexanes, heptanes, or the like, or mixtures thereof (6B) to change the polarity of the contaminated extraction solvent, in turn causing the extraction solvent to reject the extract. The second counterflow step again takes place in a packed column (7) and gives rise to an exit stream of contaminants (8B) such as hexanes and heptanes impurities, etc.

The first and second extractions steps take place at substantially ambient pressure, at about 80 °C and over a counterflow extraction period of less than about 20 minutes.

In a final step, the contaminated NMP solvent (9) is then distilled using a standard distillation column (10), which gives rise to recycled hexanes/heptanes (11B) and recycled NMP (12). The waste product obtained following recycling of the extraction solvent is adaptable for use as a boiler fuel or marine diesel oil.

It will be appreciated that the process as depicted according to Figure 5 is substantially the same as that of Figure 4, with the additional extraction solvent purification step being performed.

Often, it is found that there is a heavy contaminant in the extraction solvent/s (NMP) that is not removed other than by one or more deliberate purification steps. It is found that the contaminant may be one or more heavy hydrocarbons with a boiling
point higher than NMP. Thus the NMP can be purified by an additional simple distillation step as depicted in Figure 5 and discussed below.

[0108] Referring now to Figure 6, a separate (or in-line) means is provided for purifying the contaminated extraction solvents to purity levels that enable their re-use in subsequent iterations of the process.

[0109] In the purification step/s depicted in Figure 6, contaminated NMP (12) with remaining contaminant enters a rising film evaporator (D) that is heated generally by steam or heat transfer oil (13). The rising film evaporator is under vacuum on the NMP side. Generally the vacuum conditions will be between about -80 and -90 kPa. Generally the temperature of the rising film evaporator will be controlled to facilitate the boiling of the NMP at the desired vacuum The NMP boils off as NMP vapour (14) leaving the heavy contaminant and in condensed in the NMP vacuum condenser (E). The heavy contaminants (17) leave the rising film evaporator for use as industrial heating fuel or further refining. The recycled and purified NMP (16) is then returned to subsequent iterations of the extraction method.

[0110] In respect of each of the aspects described above, it will be appreciated that the extraction of the purified diesel (4) takes place within the first extraction step, with the second extraction step and subsequent distillation steps serving to provide a means of recycling the NMP and water solvents.

[0111] The method is adapted to be scalable to a commercial scale of greater than 1000 tons fuel per day. However, during scale-up, the method is also scalable to a pilot plant scale.

[0112] The method gives rise to yields of about 70% w/w diesel and about 15% w/w gasoline per unit plastics. However, to an appreciable extent, the recovery of fuel from the waste plastics is dictated firstly by the composition of the waste plastics and by the conditions (temperature, pressure, period) under which the pyrolysis step is effected. The purified diesel fuel is directly transferrable to commercial at-the-pump sale and

[013] Figure 7 depicts a sample of crude plastic-derived diesel following pyrolysis of the crude waste plastics. Notable features are its darkness and its opacity. This crude product is unsuitable for commercial sale at-the-pump. Figure 8 is a photograph of an extraction step in which NMP is mixed with the sample and allowed to settle out to the bottom. The impurities/contaminants dissolve out into the NMP; the relatively clear layer remaining on top is relatively pure diesel. Figure 9 depicts a sample of the final purified diesel product following the NMP extraction steps. As noted elsewhere, the fuel is directly transferrable to commercial at-the-pump sale and meets the Australian Diesel Fuel Quality Standard (Fuel Standard (Automotive Diesel) Determination 2001, as amended, made under section 21 of the Fuel Quality Standards Act 2000), as well as ASTM D975-15c and EN590 standards.

[0114] It will be appreciated that the above-described methods enable the conversion of waste plastics into a commercially useful form by way of purified diesel fuel. Moreover, the inventive method provides means for recycling any solvents used in such an extraction process.

[0115] It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the above-described embodiments, without departing from the broad general scope of the present disclosure. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.
CLAIMS:

1. A kiln for use in the production of hydrocarbon fuels from plastics, the kiln comprising:
   a reaction chamber;
   a feed inlet for feeding plastics feed material into the reaction chamber;
   a heater for heating the reaction chamber; and
   a scrubber in direct fluid communication with the reaction chamber;
   wherein the kiln is configured such that plastics feed material in the reaction chamber is heated in an absence of oxygen thereby to decompose at least a portion of the plastics feed material into a reaction chamber gas product stream comprising hydrocarbons suitable for use as fuel, and
   wherein the scrubber is configured to remove hydrocarbons in the reaction chamber gas product stream above a predetermined upper hydrocarbon range for returning to the reaction chamber for further heating in the absence of oxygen.

2. A kiln according to claim 1, in which the temperature of the reaction chamber gas product stream exiting the reaction chamber does not drop substantially before entering the scrubber.

3. A kiln according to claim 1 or claim 2, wherein scrubber is configured such that a scrubber gas stream exiting the scrubber is at a temperature of less than 350°C.

4. A kiln according to any one of the preceding claims, wherein the kiln is a cylindrical horizontal kiln comprising a cylindrical outer shell and the reaction chamber comprises an inner tube positioned concentrically in the cylindrical outer shell.

5. A kiln according to claim 4, wherein the heater comprises a heat flow medium flowing in an annulus defined between the central inner tube and outer shell, such that the heat source medium heats an outer surface of the inner tube.
6. A kiln according to claim 5, wherein the outer surface of the inner tube comprises a plurality of vortex generators for increasing heat transfer efficiency from the heat source medium to the reaction chamber.

7. A kiln according to any one of the preceding claims, further comprising a stirrer for stirring the plastic feed material in the reaction chamber.

8. A kiln according to any one of the preceding claims, further comprising a catalyst in the reaction chamber.

9. A kiln according to any one of the preceding claims, further comprising a waste particulate outlet for removing waste particulate material from the reaction chamber.

10. A system for the production of hydrocarbon fuels from plastics, the system comprising a kiln according to any one of the preceding claims.

11. A system according to claim 10, further comprising at least one hydrocarbon recovery device for recovering hydrocarbons within a predetermined hydrocarbon range.

12. The system according to claim 11, wherein the at least one hydrocarbon recovery device is one or more of: a fractionation column configured to condense diesel range hydrocarbons from a hydrocarbon gas stream; a condenser configured to condense petrol range hydrocarbons from a hydrocarbon gas stream; and/or a compression device configured to condense liquid petroleum gas (LPG) range hydrocarbons from a hydrocarbon gas stream.

13. The system according to claim 12, wherein the fractionation column is in fluid communication with a gas outlet of the scrubber.
14. The system according to claim 13, wherein the fractionation column is further configured to divert at least a portion of condensed diesel to the scrubber for use as a scrubbing liquid.

15. The system according any one of claims 12 to 14, further comprising a vacuum tower for removing water from diesel range hydrocarbons condensed by the fractionation column.

16. The system according to any one of claims 12 to 15, wherein the condenser is in fluid communication with a gas outlet of the fractionation column.

17. The system according to any one of claims 12 to 16, wherein the compression device is in fluid communication a gas outlet of the condenser.

18. An assembly for use in the production of hydrocarbon fuels from plastics, the assembly comprising:
   a kiln comprising:
   a reaction chamber;
   a feed inlet for feeding plastic feed material into the reaction chamber;
   and
   a heater for heating the reaction chamber,
   wherein the kiln is configured such that plastic feed material in the reaction chamber is heated in an absence of oxygen thereby to decompose at least a portion of the plastic feed material into a reaction chamber gas product stream comprising hydrocarbons suitable for use as fuel,
   a scrubber in fluid communication with the reaction chamber, wherein the scrubber is configured to remove hydrocarbons in the reaction chamber gas product stream above a predetermined upper hydrocarbon range and return the removed hydrocarbons to the reaction chamber for further heating in the absence of oxygen; and
   a hydrocarbon recovery device in fluid communication with the scrubber for receiving a remainder of the reaction chamber gas product stream, the hydrocarbon
recovery device being configured to remove hydrocarbons within a predetermined hydrocarbon range from said remainder.

19. A method for deriving fuel from plastics, the method comprising subjecting a quantity of plastics to a pyrolytic process, thereby to convert at least a portion of the plastics to a crude fuel; and extracting the fuel in a directly usable form by way of:

   a first extraction step comprising counterflow liquid-liquid extraction using one or more extraction solvents to extract one or more impurities from the crude fuel;

   a second extraction step comprising counterflow extraction of the resultant contaminated one or more extraction solvents from the first extraction step; and

   optionally, an extraction solvent purification step wherein the contaminated one or more extraction solvents are purified to enable their re-use in a subsequent one or more of the extraction steps.

20. A method according to claim 19, wherein the second extraction step comprises using water, alcohol, or the like, or mixtures thereof to change the polarity of the contaminated extraction solvent, in turn causing the extraction solvent to reject the extract; and then distilling the one or more polar compounds from the extraction solvent.

21. A method according to claim 19, wherein the second extraction step comprises using a light end non-polar solvent such as heptanes, hexanes, or the like, or mixtures thereof, that extract aromatics and compounds of similar polarity from the extraction solvent; and then distilling the light end solvent from the extraction solvent.

22. A method according to any one of claims 19 to 21, wherein the extraction solvent is N-methyl-2-pyrrolidone, or similar dipolar aprotic solvents such as dimethylformamide, dimethyl sulfoxide or the like.

23. A method according to any one claims 19 to 22, wherein an extraction solvent purification step is performed.
24. A method according to claim 23, comprising performing the extraction solvent purification step in a substantially continuous manner to provide for substantially continuous operation of the first and/or second extraction steps.

25. A method according to claim 19 or claim 20, wherein, in the counterflow extraction, the extraction solvent enters the top of a packed column and the crude fuel enters the bottom of the packed column.

26. A method according to claim 25, wherein the extraction solvent extracts impurities resulting in contaminated extraction solvent exiting the bottom of the packed column and purified fuel exiting the top of the packed column.

27. A method according to claim 26, wherein contaminated extraction solvent is mixed with water, alcohol, or the like, or mixtures thereof which causes the non-polar compounds such as aromatics to come out of solution.

28. A method according to claim 27, wherein impurity compounds flow off the extraction solvent which is contaminated with the water.

29. A method according to claim 28, wherein water is distilled out of the extraction solvent using conventional rising film evaporators.

30. A method according to claim 29, wherein both water and the extraction solvent are recycled.

31. A method according to claim 19 or claim 21, wherein, in the counterflow extraction, the extraction solvent enters the top of a packed column and the crude fuel enters the bottom of the packed column.

32. A method according to claim 31, wherein the extraction solvent extracts impurities resulting in contaminated extraction solvent exiting the bottom of the packed
column and purified fuel exiting the top of the packed column.

33. A method according to claim 32, wherein contaminated extraction solvent is pumped to another counterflow extraction set-up which uses the light end non-polar solvent to extract aromatics, sulfur compounds and similar from the extraction solvent.

34. A method according to claim 33, wherein the light end non-polar solvent is distilled and recycled leaving concentrated aromatics, sulfur compounds and similar and clean extraction solvent.

35. A method according to claim 34, wherein both the light end non-polar solvent and the extraction solvent are recycled.

36. A method according to any one of claims 19 to 35, wherein the fuel is a diesel blend.

37. A method according to any one of claims 19 to 36, wherein the pyrolytic process by which the plastics are converted to the crude fuel takes place at about 450 °C, over a period of about 30 minutes.

38. A method according to any one of claims 19 to 37, wherein the first and second extractions steps take place at substantially ambient pressure, at about 80 °C and over a counterflow extraction period of less than about 20 minutes.

39. A method according to claim 19, wherein the extraction solvent is N-methyl-2-pyrrolidone (NMP).

40. A method according to any one of claims 19 to 39, wherein the waste product obtained following recycling of the extraction solvent is adaptable for use as a boiler fuel or marine diesel oil, or can be stored.
41. A method according to any one of claims 19 to 40, wherein the extraction solvent purification step comprises the contaminated one or more extraction solvents entering a rising film evaporator at between about -80 and -90 kPa.

42. A method according to any one of claims 19 to 40, wherein the crude fuel is a hydrocarbon fuel obtained from plastics processed using a kiln according to any one of claims 1 to 9, a system according to any one of claims 10 to 17 or an assembly according to claim 18.

43. A diesel blend fuel when obtained by a method according to any one of claims 19 to 42.

44. Recycled one or more extraction solvents when obtained by a method according to any one of claims 19 to 42.
A. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>Further documents are listed in the continuation of Box C</td>
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* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier application or patent but published on or after the international filing date
  "L" document may throw doubts on priority claim(s) or which is cited to establish the publication date of another document to one of ordinary skill in the art
  "O" document referring to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed

   "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
   "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
   "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
   "&" document member of the same patent family

Date of the actual completion of the international search: 10 April 2017
Date of mailing of the international search report: 10 April 2017

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<td>US 645 1197 B1 (KALNES) 17 September 2002 Claims; figure</td>
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<td>US 4589973 A (MINDEN) 20 May 1986 Columns 4-5; figure 2</td>
<td>1-7, 9-13, 18</td>
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Box No. II  Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. □ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:
   the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including

2. □ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. □ Claims Nos:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III  Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Supplemental Box for Details

1. □ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. □ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. □ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. □ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

□ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

□ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

X□ No protest accompanied the payment of additional search fees.
Supplemental Box

**Continuation of: Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1-18 and in part claims 42-44 are directed to a kiln or assembly comprising a kiln in which the kiln is configured to heat plastic in the absence of oxygen producing gas product and a scrubber is configured to remove hydrocarbons in the reaction chamber gas product above a predetermined upper hydrocarbon range and return the removed hydrocarbons to the kiln. The feature of a scrubber is configured to remove hydrocarbons in the reaction chamber gas product above a predetermined upper hydrocarbon range and return the removed hydrocarbons to the kiln is specific to this group of claims.

- Claims 19-41 and in part claims 42-44 are directed to a method for deriving fuel from plastics, the method comprising subjecting a quantity of plastics to a pyrolytic process, thereby to convert at least a portion of the plastics to a crude fuel; and extracting the fuel in a directly usable form by way of: a first extraction step comprising counterflow liquid-liquid extraction using one or more extraction solvents to extract one or more impurities from the crude fuel; a second extraction step comprising counterflow extraction of the resultant contaminated one or more extraction solvents from the first extraction step. The feature of a first extraction step comprising counterflow liquid-liquid extraction using one or more extraction solvents to extract one or more impurities from the crude fuel; a second extraction step comprising counterflow extraction of the resultant contaminated one or more extraction solvents from the first extraction step is specific to this group of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied a priori.
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.