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(71) Applicant: **United Initiators GmbH & Co. KG**
82049 Pullach (DE)

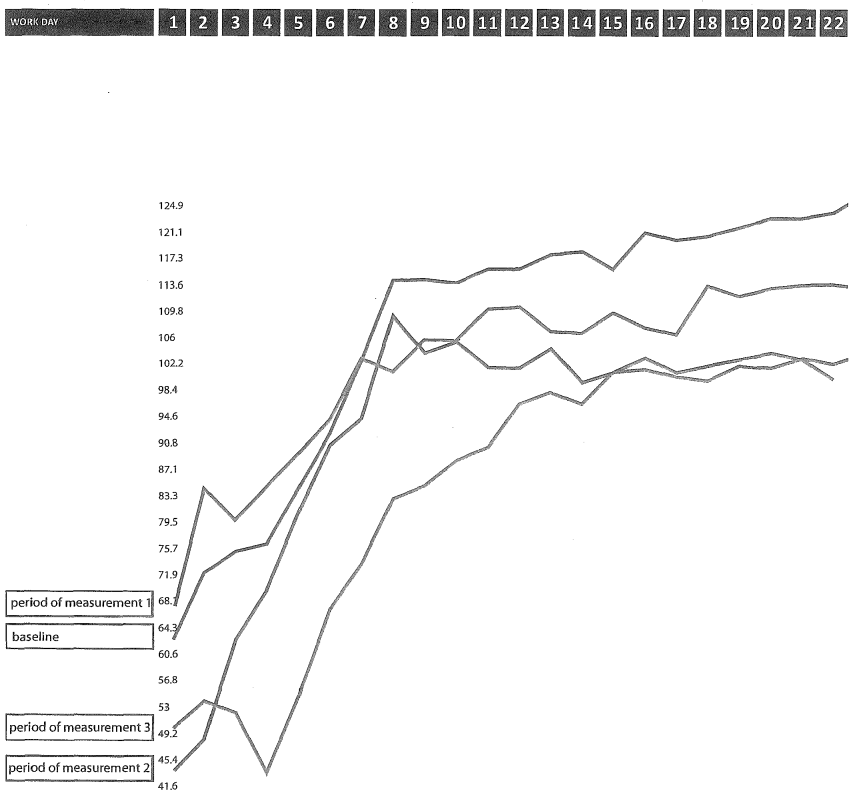
(72) Inventor: **Volpert, Edgar**
81549 München (DE)

(74) Representative: **Dey, Michael et al**
Weickmann & Weickmann
Patentanwälte PartmbB
Postfach 860 820
81635 München (DE)

(54) **USE OF A FUEL ADDITIVE IN DIESEL FUEL FOR REDUCING FUEL CONSUMPTION IN A DIESEL ENGINE**

(57) The present invention relates to the use of a diesel fuel additive comprising a peroxide for reducing the fuel consumption in a diesel engine.

Figure 1



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Description

[0001] The present invention relates to the use of a diesel fuel additive, comprising a peroxide for reducing fuel consumption in a diesel engine.

[0002] Combustion engines, in particular diesel engines, are important in various fields for generating energy. Due to their high robustness and durability as well as their excellent operating performance, they are essential energy sources for example in power generators, agricultural and construction machines, drilling rigs, buses, trucks, trains and ships. Combustion engines produce energy from fuels, so that their operational costs are influenced by the fuel price as well as the fuel consumption.

[0003] It is desired to reduce the fuel consumption in an engine inter alia to reduce operational costs. Reduction of the fuel consumption in an engine means that for the same energy provided by the engine less fuel is required. Consequently, an internal combustion engine with reduced fuel consumption provides energy over a longer period of time compared to the same internal combustion engine without reduced fuel consumption. Hence, with the same amount of fuel an internal combustion engine with reduced fuel consumption provides more energy compared to an internal combustion engine with normal fuel consumption.

[0004] The published patent application EP 2 780 435 A1 describes the use of TBHP as fuel additive for reducing carbon monoxide and/or hydrocarbon emission as well as increasing the cetane number.

[0005] It was an object of the present invention to achieve a reduction of the fuel consumption in diesel engines.

[0006] This object is solved with a fuel additive for diesel fuels comprising a peroxide, particularly tert-butyl hydroperoxide (TBHP).

[0007] The invention therefore relates to the use of a fuel additive comprising a peroxide in a diesel fuel for reducing the fuel consumption in a diesel engine.

[0008] Surprisingly, it has been found that by using peroxides, wherein TBHP is particularly preferred, a reduction of the consumption of diesel fuel in diesel engines is effected.

[0009] The use of a peroxide-containing fuel additive particularly provides a reduction of diesel fuel consumption by at least 5 %, more preferably by at least 7%, yet more preferably by at least 10%, even more preferably by at least 13% compared to a similar diesel fuel without fuel additive.

[0010] This is impressively demonstrated in extensive comparative tests and long-term measurements in Examples 1-4 and Figures 1-2 of this application.

[0011] A fuel additive is a composition added to a fuel, preferably in amounts of 0.001 to 50 wt.%, more preferably between 0.01 to 25 wt.%, more preferably between 0.1 to 10 wt.% related to the total weight of the fuel. By adding a fuel additive to the fuel, the fuel additive and the fuel preferably form a solution.

[0012] The fuel additive to be used according to the invention comprises a peroxide, particularly an organic peroxide and preferably TBHP.

[0013] In general various organic peroxides can be used as fuel additives. Preferred is the use of a fuel additive comprising at least one hydroperoxide, dialkylperoxide or/and a cyclic or acyclic ketone peroxide.

[0014] Hydroperoxides, in particular alkyl-, acyl- or/and arylhydroperoxides, have the general structural formula R-O-O-H.

[0015] Dialkylperoxides, in particular cyclic and acyclic dialkylperoxides, have the general structural formula R^1-O-O-R^2. In cyclic dialkylperoxides the residues R^1 and R^2 together form a 4 to 10 membered cycle, more preferably a 5 to 7 membered cycle.

[0016] Cyclic ketone peroxides have the general structural formula $(R^1R^2C(\text{-O-O-}))_n$, wherein n can be an integer from 2 to 6, the peroxidic bond is formed between the C-atoms to form a cycle, and R^1 and R^2 represent identical or different organic residues.

[0017] Acyclic ketone peroxides have the general structural formula $R^1R^2C(\text{-O-O-H})\text{-O-O-}C(\text{-O-O-H})R^3R^4$, wherein R^1, R^2, R^3 and R^4 represent identical or different organic residues.

[0018] The residues R, R^1, R^2, R^3 and R^4 represent each independently an organic residue, in particular a hydrocarbon residue which can be substituted with 1 to 3 heteroatoms.

[0019] In particular, the residues R, R^1, R^2, R^3 and R^4 represent each independently

acyclic linear chain alkyl, preferably having 1 to 20, preferably 3 to 10 carbon atoms and can be unsubstituted or substituted with at least one -OMe, -OH, aryl or/and heteroaryl;

acyclic branched chain alkyl, preferably having 1 to 20, preferably 3 to 10 carbon atoms and can be unsubstituted or substituted with at least one -OMe, -OH, aryl or/and heteroaryl;

acyl, wherein acyl represents a moiety having the structural formula RC(O)-;

aryl, wherein aryl is an aromatic moiety with 6 to 10 carbon atoms, which can be unsubstituted or substituted with -OMe or/and -OH;

heteroaryl, wherein heteroaryl is an aromatic moiety with 4 to 10 carbon atoms comprising one or more heteroatoms, particularly nitrogen or/and oxygen in the aromatic system, and can be unsubstituted or substituted with -OMe or/and

-OH; or
cyclic alkyl, preferably having 3 to 10, more preferably 5 to 8 carbon atoms forming a cycle and can be unsubstituted or substituted with a least one -OMe, -OH, acyclic linear chain alkyl or/and acyclic branched chain alkyl.

[0020] In a preferred embodiment the fuel additive comprises tert-butylhydroperoxide (TBHP), cumene hydroperoxide, methylethyl ketone peroxide, in particular cyclic or acyclic methylethyl ketone peroxide, acetone peroxide, tert-amyl hydroperoxide (TAHP), di-tert-butyl peroxide (DTBP), tert-butyl peroxybenzoate (TBPB), 1,1-Di-(tert-butylperoxy)-cyclohexan (CH) or tetramethyl-dioxa-cyclohexane (TMDOCH) or mixtures thereof.

[0021] Specifically when using a fuel additive comprising hydroperoxide, dialkylperoxide or/and cyclic or acyclic ketone peroxide, particularly tert-butyl hydroperoxide (TBHP), cumene hydroperoxide, methylethyl ketone peroxide, in particular cyclic and/or acyclic methylethyl ketone peroxide, acetone peroxide, tert-amyl hydroperoxide (TAHP), di-tert-butyl peroxide (DTBP), tert-butyl peroxybenzoate (TBPB), 1,1-Di-(tert-butylperoxy)-cyclohexan (CH) or/and tetramethyl-dioxa-cyclohexane (TMDOCH), a significant reduction of diesel fuel consumption in diesel engines has been observed.

[0022] Most preferably the fuel additive comprises TBHP.

[0023] Organic peroxides are thermally unstable compounds, which decompose exothermically with cleavage of the peroxidic oxygen bond. Therefore, for the safe handling or safe transport of organic peroxides they must, for safety considerations often be phlegmatised or are produced industrially already in dilution.

[0024] Commercially available peroxide preparations often contain large amounts of water as phlegmatiser, have insufficient thermal or chemical stability or cannot be used commercially as a fuel additive due to the raw materials or production processes used. Preferably, peroxides phlegmatised with water should be avoided as a fuel additive, because water does not mix with the fuel but forms a two-phase system.

[0025] Therefore, preferably an anhydrous fuel additive is used. Anhydrous means that the content of water in the fuel additive is < 5 wt.%, particularly < 1 wt. %, yet more preferably < 0.3 wt.%, most preferably < 0.01 wt%.

[0026] By using anhydrous peroxide, which is miscible with diesel fuel, the formation of an undesirable second aqueous phase can be avoided. The fuel additive, in addition to a peroxide preferably comprises an anhydrous organic solvent. Polar and non-polar solvents can be used. Examples of suitable non-polar solvents are alkanes, in particular aliphatic hydrocarbons such as isododecane, isooctane, decane, nonane and/or n-octane or mixtures of different aliphates. In particular, suitable examples of solvents are diesel and kerosene. Further examples of suitable hydrocarbons are cyclic and acyclic hydrocarbons with 5 to 12, preferably 6 to 10 carbons either saturated or unsaturated. Examples of polar solvents are particularly oxygen-containing solvents, such as, for example, esters and alcohols. Suitable esters used as solvents are in particular phthalates and 2,2,4-trimethyl-1,3-pentanediol diisobutyrate (TXIB). Alkyl alcohols are preferably used as solvents, particularly C1-C8 alkyl alcohols, more preferably C2-C6 alkyl alcohols, yet more preferably butanol and most preferably tert-butanol (TBA). By using alcohols and particularly tert-butanol, the oxygen content in the fuel additive is increased further, which is desirable.

[0027] Particulary preferred is a fuel additive comprising TBHP and an organic solvent, particularly tert-butanol (TBA).

[0028] According to the invention the additive containing peroxide is added to a diesel fuel. Diesel fuels can comprise, for example, diesel, biodiesel or marine diesel.

[0029] Preferably the diesel fuel containing the peroxide-containing diesel additive is anhydrous. Anhydrous means that the diesel fuel containing the peroxide-containing diesel additive has a total content of water of < 5 wt.%, particularly < 1 wt.%, more preferably < 0.3 wt.%, yet more preferably < 0.1 wt.%, even more preferably < 0.03 wt.%, more preferably < 0.01 wt.%, yet even more preferably < 0.001 wt.%, most preferably < 0.0001 wt.%.

[0030] Particularly good results are obtained when the additive containing peroxide is added to a fuel exhibiting a low diesel grade, such as various marine diesel or diesel as used in many non-EU countries.

[0031] Low diesel grades or diesel fuels of a low quality have a cetane number without fuel additive of < 50, more preferred < 45, yet more preferred ≤ 40, whereas higher diesel qualities have a cetane number ≥ 50, more preferred ≥ 51. Low grade diesel fuels have a minimum cetane number without fuel additive of > 20, preferably > 25, more preferably > 30. The cetane number can be determined according to ASTM-D613, for example.

[0032] The cetane number is a characteristic parameter for the combustion quality of diesel fuel. The cetane number is a measure of the ease of ignition or the ignition delay, that is to say the time between the start of fuel injection and the start of combustion. Rapid ignition followed by uniform combustion is advantageous. The higher the cetane number, the shorter the ignition delay and the better the combustion quality.

[0033] Now it has been found that the use of a peroxide-containing fuel additive provides a significant reduction of fuel consumption in a diesel engine, when low grade diesel qualities such as commercially available US diesel, are applied. In this respect, peroxides are also suitable e.g. as fuel additives for reducing fuel consumption in regions, where typically low grade diesel fuels are applied.

[0034] Preferably the peroxide-containing fuel additive applied according to the invention increases the cetane number of a fuel with fuel additive by at least 2, more preferred by at least 3, yet more preferred by at least 5, most preferred at least by 7 compared to the cetane number of the same fuel without fuel additive.

[0035] A diesel fuel admixed with the peroxide-containing additive can be applied in diesel engines such as used in

automotives or ships or provided for stationary diesel engines to generate energy. A particularly significant reduction of fuel consumption is effected in low compression diesel engines. Compared to modern diesel engines complying with current Euro 5 standard, low compression diesel engines exhibit a lower compression ratio. Modern high compression diesel engines exhibit a compression ratio of at least 19:1, more preferred at least 21:1. In contrast, low compression diesel engines exhibit a compression ratio of less than 19:1, particularly of less than 18:1 and preferably less than 16:1 auf.

[0036] The compression ratio describes the ratio of the total cylinder chamber prior to compression to the remaining space after compression. The compression of the cylinder chamber causes a rise in temperature in the cylinder chamber. A high compression ratio provides easy self-ignition.

[0037] Further, the size of displacement per cylinder determines the quality of combustion in a diesel engine. A particularly significant reduction of fuel consumption by addition of a peroxide, particulary TBHP, is discovered in engines with a large displacement per cylinder, particularly for a displacement of at least 1000 cm^3, more preferably at least 2000 cm^3, yet even more preferably at least 3000 cm^3 per cylinder. A large displacement per cylinder effects worse mixing or blending of the fuel with air. Thus, without additive, there is worse or incomplete combustion of the fuel.

[0038] Displacement or displaced volume describes the enclosed volume of a cylinder in a combustion engine, which results from the stroke of a single piston and the effective piston cross section. The cylinder displacement hence is the volume displaced by the stroke of the piston in a combustion engine.

[0039] The amount of peroxide, particularly TBHP, in the fuel additive is preferably at least 10 wt.%, more preferably at least 30 wt.%, yet more preferably at least 40 wt.%, most preferably at least 50 wt.%. Pure peroxide is not preferred for safety considerations. The amount of peroxide, particularly TBHP in the fuel additive is therefore preferably up to 90 wt.%, more preferably up to 75 wt.% and most preferably up to 60 wt.%. The amount of anhydrous organic solvent, particularly alcohols and preferably tert-butanol (TBA), is accordingly at least 10 wt.%, more preferably at least 25 wt.% and most preferably at least 40 wt.% and up to 90 wt.%, more preferably up to 70 wt.% and most preferably up to 50 wt.%.

[0040] A fuel additive that comprises 30 to 70 wt.% peroxide in 70 to 30 wt.% alcohol has been shown to be particularly suitable and accordingly most preferred. A fuel additive that comprises 50 to 60 wt.% peroxide in 60 to 50 wt.% alcohol is yet more preferred. A fuel additive that comprises 55 wt.% peroxide and 45 wt.% alcohol is most preferred. Due to the production process, peroxides can be phlegmatised by an oxygen-containing solvent, preferably in an alcohol, particularly in tert-butanol, thereby improving safety during transport and further handling.

[0041] A fuel additive that comprises 30 to 70 wt.% TBHP in 70 to 30 wt.% tert-butanol (TBA) has been shown to be particularly preferred. A fuel additive that comprises 50 to 60 wt.% TBHP in 60 to 50 wt.% tert-butanol is yet more preferred. A fuel additive that comprises 55 wt.% TBHP and 45 wt.% tert-butanol is most preferred.

[0042] It has been found that a reduction of fuel consumption can be achieved even with small amounts of fuel additive.

[0043] The peroxide, particularly TBHP, is applied in an amount of 0.001 to 10 wt. %, more preferably from 0.01 to 8 wt.%, more preferably from 0.025 to 5 wt. %, yet more preferably from 0.055 to 4 wt.% most preferably from 0.1 to 3 wt. %, based on the total weight of the fuel.

[0044] In a preferred embodiment the invention relates to the use of a diesel fuel additive in a diesel fuel for reducing fuel consumption in a diesel engine characterized in that the fuel additive comprises an organic peroxide being applied in an amount from 0.025 to 10 wt.%, in particular from 0.1 to 3 wt.%, based on the total weight of the fuel.

[0045] In another preferred embodiment the invention relates to the use of a diesel fuel additive in a diesel fuel for reducing fuel consumption in a diesel engine characterized in that the fuel additive comprises an anhydrous organic peroxide being applied in an amount from 0.025 to 10 wt.%, in particular from 0.1 to 3 wt.%, based on the total weight of the fuel.

[0046] In yet another preferred embodiment the invention relates to the use of a diesel fuel additive in a diesel fuel for reducing fuel consumption in a diesel engine characterized in that the fuel additive comprises an anhydrous organic peroxide being applied in an amount from 0.025 to 10 wt.%, in particular from 0.1 to 3 wt.%, based on the total weight of the fuel and the diesel fuel has a cetane number of < 45 without fuel additive.

[0047] In a particular preferred embodiment the invention relates to the use of a diesel fuel additive in a diesel fuel for reducing fuel consumption in a diesel engine characterized in that the fuel additive comprises anhydrous TBHP and TBA.

[0048] In another preferred embodiment the invention relates to the use of a diesel fuel additive in a diesel fuel for reducing fuel consumption in a diesel engine characterized in that the fuel additive comprises anhydrous TBHP and TBA, wherein TBHP is applied in an amount from 0.025 to 10 wt.%, in particular from 0.1 to 3 wt.%, based on the total weight of the fuel.

[0049] In yet another preferred embodiment the invention relates to the use of a diesel fuel additive in a diesel fuel for reducing fuel consumption in a diesel engine characterized in that the fuel additive comprises anhydrous TBHP and TBA wherein TBHP is applied in an amount from 0.025 to 10 wt.%, in particular from 0.1 to 3 wt.%, based on the total weight of the fuel and the diesel fuel has a cetane number of < 45 without fuel additive.

[0050] It is also possible according to the invention to combine the fuel additive and/or the fuel with other components. Preference is given, for example, to an additive comprising at least two peroxides, particularly selected from hydroperoxides, dialkyl peroxides and/or cyclic or acyclic ketone peroxides. Particularly preferred is tert-butyl hydroperoxide

(TBHP) in combination with a further peroxide, particularly selected from cumene hydroperoxide, di-tert-butylperoxide (DTBP), methylethyl ketone peroxide, in particular cyclic and acyclic methylethyl ketone peroxide, acetone peroxide, tert-amyl hydroperoxide (TAHP), di-tert-butyl peroxide (DTBP), tert-butyl peroxybenzoate (TBPB), 1,1-Di-(tert-butylperoxy)-cyclohexan (CH) or/and tetramethyl-dioxa-cyclohexane (TMDOCH). Further, an additive is preferred that comprises at least one peroxide and additionally tert-butylalcohol or/and 2-ethylhexylnitrate (2-EHN).

[0051] Preferably, reduction of fuel consumption in an engine can be observed by continuously or constantly using the peroxide-containing fuel additive during the entire operation time.

[0052] Preferably, reduction in fuel consumption can be observed when the fuel containing the peroxide-containing fuel additive is continuously used in a diesel engine for a runtime or operation time of at least 100 hours, preferred at least 170 hours, more preferred at least 240 hours and most preferred at least 310 hours.

[0053] Preferably, reduction in fuel consumption can be observed when the fuel containing the peroxide-containing fuel additive is continuously used in a diesel engine for a runtime or operation time of at least 4 days, preferred at least 7 days, more preferred at least 10 days and most preferred at least 13 days.

[0054] It is less preferred, although also possible, that the fuel consumption in an engine can be reduced by adding the fuel containing the peroxide-containing fuel additive in intervals. Thereby it is understood, that certain amounts of fuel with the peroxide-containing fuel additive are added in certain time intervals while using fuel without the peroxide-containing fuel additive otherwise. Preferably, the amount of added fuel with the peroxide-containing fuel additive is at least 10 liters, preferably at least 20 liters, more preferred at least 40 liters and most preferred at least 60 liters. Preferably, the fuel containing the peroxide-containing fuel additive is used for 10 to 1000 hours, preferably 50 to 500 hours, more preferred 100 to 250 hours alternating with using the fuel without the peroxide-containing fuel additive for 10 to 1000 hours, preferably 50 to 500 hours, more preferred 100 to 250 hours.

[0055] It was further observed that the use of a peroxide-containing fuel additive provides prevention, reduction or removal of undesired deposits or contaminants in a diesel engine. Undesired deposits in an engine can be formed due to incomplete combustion of the fuel, impurities in the fuel or/and suction of impurities from air. As a result thereof, apart from volatile gases, also finest solids or particles are formed. These particles can deposit inter alia on the fuel injection valves and channels of the engine. Deposits at the injection valves hamper that diesel fuel completely reaches the combustion chamber of the engine. The use of a peroxide-containing diesel additive removes already existing deposits or contaminants and prevents the formation of new deposits or contaminants in the engine.

[0056] Examples of deposits or contaminants comprise small particles, soot or/and glycol.

[0057] Further, it was observed that the use of a peroxide-containing fuel additive provides a reduction in friction and wear of the diesel engine. Reduction in friction and wear can be achieved when a fuel additive with high lubrication is used. The HFRR (high frequency reciprocating rig) score is a characteristic parameter for the lubrication of a fuel or a fuel additive. The HFRR score can be determined according to ASTM-D6078 and ASTM-D6079, for example. A high HFRR score is determined for a fuel or fuel additive with bad lubrication as for example untreated ultra-low sulfur diesel having a HFRR score of 636. A high HFRR score results in high friction and wear by the fuel or fuel additive compared to a fuel or fuel additive with a low HFRR score. According to the Engine Manufacturers Association the HFRR score has to be desirably below 460.

[0058] Preferably, the fuel with peroxide-containing fuel additive has a HFRR score of at most 400, more preferred at most 370 and most preferred at most 330.

[0059] Preferably, the peroxide-containing fuel additive applied lowers the HFRR score of a fuel with fuel additive by at least 70, more preferably at least 140 and most preferably at least 210 compared to the same fuel without fuel additive.

[0060] Preferably, the peroxide-containing fuel additive applied lowers the HFRR score of a fuel with fuel additive by at least 30, more preferably at least 60 and most preferably at least 90 in comparison to the limit value of Engine Manufacturers Association.

[0061] Also part of this invention is a method for reducing diesel fuel consumption in a diesel engine wherein a fuel additive comprising a peroxide is added to the diesel fuel.

Example 1

Reduction of fuel consumption with TBHP and TBA as fuel additive

[0062] To a conventional US base diesel fuel (cetane number = 42) was added 0.25 wt.% of a fuel additive consisting of TBHP (55 wt.%) and TBA (45 wt.%). The total amount of TBHP added to the diesel fuel is 0.14 wt.%.

[0063] By addition of the fuel additive to the above described diesel fuel the cetane number is increased from 42 (without fuel additive) to 48 (with fuel additive).

[0064] The test engine used was a Caterpillar D3512-C V12 diesel engine exhibiting a total displacement of 58560 cm^3, as well as a displacement per cylinder of 4880 cm^3 and a compression ratio of 14.7:1. The test engine was used in a drilling rig.

[0065] In a comparative test the consumption of the above mentioned US base diesel fuel was measured without and with diesel fuel additive consisting of TBHP and TBA in the Caterpillar D3512-C diesel engine over a continuous period of time of 22 days. The measurement of fuel consumption of the US base diesel fuel without diesel fuel additive (baseline) is the average of 14 wells tested with the diesel engine. In the period of measurement 1 the fuel additive has been applied for the first time to the diesel engine. Period of measurement 1 is followed by period of measurement 2, which in turn is followed by period of measurement 3. In the period of measurement 2 and 3 the same diesel engine has been used as for period of measurement 1.

[0066] In the following table 1 the fuel consumption is indicated as consumption of litres per hour (l/h) as average value for the respective day. Figure 1 illustrates this result.

Table 1

Comparison of the reduction of fuel consumption without and with TBHP and TBA as fuel additive				
		Period of measurement 1	Period of measurement 2	Period of measurement 3
day	US base diesel fuel without TBHP in TBA (average consumption in l/h)	US base diesel fuel with TBHP in TBA (average consumption in l/h)	US base diesel fuel with TBHP in TBA (average consumption in l/h)	US base diesel fuel with TBHP in TBA (average consumption in l/h)
1	62.26	67.98	42.96	50
2	72.52	84.82	48.60	53.97
3	75.81	80.51	62.91	52.46
4	80.66	94.25	70.29	43.94
5	92.73	103.52	81.19	54.92
6	99.01	97.77	91.10	66.96
7	106.13	106.36	94.44	73.50
8	114.72	110.64	109.69	82.89
9	114.61	107.15	104.69	84.97
10	116.35	106.28	105.79	88.61
11	116.24	110.26	101.82	90.80
12	119.83	111.13	101.70	96.82
13	120.44	107.80	104.96	98.49
14	117.64	107.42	99.62	96.93
15	121.80	110.26	100.64	101.06
16	120.70	108.36	103.44	101.51
17	121.31	111.24	101.25	101.02
18	122.48	114.12	102.31	100.08
19	123.69	112.72	104.39	102.50
20	123.73	113.59	104.05	101.97
21	124.26	114.31	103.10	103.67
22	122.97	114.38	100.83	101.74
average	108.63	104.31	92.69	84.03

[0067] In the course of testing, an increase of fuel consumption was observed for fuel both with and without a fuel additive consisting of TBHP and TBA. Due to the use of the test engine in a drilling rig, the increase of fuel consumption depended on the earth drilled. With longer drilling periods, the drill advanced into deeper and more rigid layers of earth. In order to advance through more rigid layers of earth, the test engine needed more energy, hence consumed more

fuel. Although the absolute values of fuel consumption are increasing during drilling, the relative values of fuel consumption of the fuel without fuel additive compared to the fuel with fuel additive are decreasing.

[0068] Over the total period of measurement of 22 days an average consumption of 108,63 l/h was yielded for US base diesel fuel without fuel additive and of 104.31 l/h (period of measurement 1), 92.69 l/h (period of measurement 2) and 84.03 l/h (period of measurement 3) was yielded for the same US base diesel fuel with fuel additive. This corresponds to an average fuel saving of 4.32 l or 3.97% (period of measurement 1), 15.94 l or 14.67% (period of measurement 2) and 24.6 l or 22.65% (period of measurement 3) per hour measured.

[0069] The increase of fuel consumption during day 1-6 in period of measurement 1 is due to removal of impurities and deposits from the engine. From day 7 in period of measurement 1 on, the engine is cleaned to such an extend that reduction in fuel consumption is observed.

[0070] In a longer test over a period of 1306 hours 154662 l US base diesel fuel without fuel additive was consumed and 131684 l US base diesel fuel with fuel additive. This corresponds to a total fuel saving of 22978 l or 14.86%.

Example 2

Reduction of fuel consumption with TBHP and TBA as fuel additive

[0071] To a US marine diesel (cetane number = 40) was added 0.25 wt.% of a fuel additive consisting of TBHP (55 wt.%) and TBA (45 wt.%). The total amount of TBHP added to this diesel fuel is 0.14 wt.%.

[0072] The test engine used was a John Deere 6081 PowerTech 8.1 L, 6 cylinder, marine engine exhibiting a total displacement of 8100 cm^3, as well as a displacement per cylinder of 1350 cm^3 and a compression ratio of 15.7:1.

[0073] In a comparative test the consumption of the above mentioned US marine diesel was measured with and without diesel additive consisting of TBHP and TBA in the John Deere 6081 PowerTech 8.1 L marine diesel engine over a period of time of 25 days. The average consumption of diesel fuel without fuel additive was 25.55 l/h. The average consumption of the diesel fuel with diesel fuel additive was reduced compared to the diesel fuel without fuel additive during the period of measurement 1 (day 11-15) by 2.1%, during the period of measurement 2 (day 16-20) by 8.9% and during the period of measurement 3 (day 21-25) by 17.9%. This test result is illustrated in Figure 2.

[0074] The increase of fuel consumption during day 1-5 and day 6-10 is due to removal of impurities and deposits from the engine which impurities clog the engine filter. Clogged filters have been changed on day 6, 11 and 16. From day 13 on, the engine is cleaned so that reduction in fuel consumption is observed.

Example 3

Reduction of fuel consumption with TBHP and TBA as fuel additive

[0075] To a conventional US base diesel fuel (cetane number = 42) was added 0.25 wt.% of a fuel additive consisting of TBHP (55 wt.%) and TBA (45 wt. %). The total amount of TBHP added to the diesel fuel is 0.14 wt.%.

[0076] In comparative tests the average consumption of the above mentioned base diesel fuel was measured without and with diesel fuel additive consisting of TBHP and TBA in diesel engines of various types of buses. In the following table 2 the average consumption is indicated as consumption in litres per 100 km for various buses.

Table 2

Comparison of the reduction of fuel consumption without and with TBHP and TBA as fuel additive in various types of buses.					
Bus No.	Bus description	US base diesel fuel without TBHP in TBA (average consumption in l/100 km)	US base diesel fuel with TBHP in TBA (average consumption in L/100 km)	total km travelled with a US base diesel fuel with TBHP in TBA	reduction of average consumption (in %)
1	1995 Amtran International V 14.5 tons	47.47	40.94	676	14
2	2002 Amtran International V 14.5 tons	97.51	69.73	686	28

(continued)

Comparison of the reduction of fuel consumption without and with TBHP and TBA as fuel additive in various types of buses.					
Bus No.	Bus description	US base diesel fuel without TBHP in TBA (average consumption in l/100 km)	US base diesel fuel with TBHP in TBA (average consumption in L/100 km)	total km travelled with a US base diesel fuel with TBHP in TBA	reduction of average consumption (in %)
3	2008 Caterpillar I-6 16.5 tons	47.00	41.37	3156	12
4	2008 Caterpillar I-6 16.5 tons	44.17	40.80	3125	7.7
5	2008 Caterpillar I-6 16.5 tons	43.20	39.76	3323	8.0
6	2008 Caterpillar I-6 16.5 tons	44.59	40.24	2790	9.8
7	2008 Caterpillar I-6 16.5 tons	44.51	39.97	2771	10
8	2008 Caterpillar I-6 16.5 tons	40.73	28.21	3294	31
9	2008 Caterpillar I-6 16.5 tons	46.35	27.04	3663	42
10	2009 Mercedes Benz I-6 16.5 tons	38.59	35.77	2597	7.3
11	2009 Mercedes Benz I-6 16.5 tons	40.73	37.72	2294	7.4
12	2009 Mercedes Benz I-6 16.5 tons	47.19	42.41	3489	10
13	2009 Mercedes Benz I-6 16.5 tons	46.53	28.38	2246	39

Example 4

Reduction in friction by using TBHP and TBA as a fuel additive

[0077] To an untreated ultra-low sulfur diesel (cetane number = 42) was added 0.25 wt.% of a fuel additive consisting of TBHP (55 wt.%) and TBA (45 wt.%). The total amount of TBHP added to the diesel fuel is 0.14 wt.%.

[0078] In comparative tests the HFRR score of the above mentioned untreated ultra-low sulfur diesel was measured without and with different diesel fuel additives. In the following table 3 the HFRR score of untreated ultra-low sulfur diesel is indicated as well as the HFRR score of ultra-low sulfur diesel with different fuel additives. Moreover, the HFRR score of the fuel with fuel additive is compared to the fuel without fuel additive.

Table 3

HFRR score of base fuel without as well as with diesel additives			
	Additive / Fuel	HFRR score	Reduction
	Standard of the Engine Manufacturers Association (desired)	< 460	
	Untreated ultra-low sulfur diesel	636	
1	2-EHN (25.3 - 38.6 wt.%); petroleum naphta (27.2 - 41.3 wt.%) trimethylbenzene (0.4 - 1.96 wt.%), naphthalene (3.12 wt.%), 2-ethylhexanol (0.4 - 1.96 wt.%)	447	189
2	2-EHN (10 - 19.9 wt.%), petroleum naphta (60 - 69 wt.%) trimethylbenzene (20 - 29 wt%)	461	175
3	2-EHN (30 - 60 wt.%), light aromatic petroleum naphta (30 - 60 wt.%) 1,2,4-trimethylbenzene (10 - 30 wt.%)	470	166
4	1,2,4-trimethylbenzene (30 - 60 wt.%) trimethylbenzene (30 - 60 wt.%) solvent naphta, heavy aromatic (5 - 10 wt.%)	488	148
5	Distillates petroleum, hydrotreated light (30 - 50 wt.%), 2-EHN (20 - 30 wt.%), naphta (petroleum), heavy aromatic 10 - 30 wt.%)	603	33
6	TBHP (55 wt.%), TBA (45 wt.%)	316	320

[0079] The diesel additive consisting of TBHP and TBA resulted in a reduction of the HFRR score of 320 and is below the standard of the Engine Manufacturers Association.

Claims

1. Use of a fuel additive in a diesel fuel for reducing fuel consumption in a diesel engine,
characterized in that
the fuel additive comprises a peroxide.

2. The use of a fuel additive according to claim 1,
characterized in that
the fuel additive comprises at least an organic peroxide, in particular a hydroperoxide, dialkylperoxide or/and a cyclic or acyclic ketone peroxide.

3. The use of a fuel additive according to any one of the previous claims,
characterized in that
the fuel additive comprises tert-butylhydroperoxide (TBHP), cumene hydroperoxide, methylethylketonperoxide, acetone peroxide, tert-amyl hydroperoxide (TAHP), di-tert-butyl peroxide (DTBP), tert-butyl peroxybenzoate (TBPB), 1,1-Di-(tert-butylperoxy)-cyclohexan (CH) or/and tetramethyl-dioxa-cyclohexane (TMDOCH).

4. The use of a fuel additive according to any one of the previous claims,
characterized in that
the fuel additive comprises TBHP.

5. The use of a fuel additive according to any one of the previous claims,
characterized in that
the fuel additive additionally comprises a solvent, in particular selected from alcohols, in particular tert-butyl alcohol, hydrocarbons, in particular isodedecan, diesel, kerosene or 2,2,4-trimethyl-1,3-pentanediol diisobutyrate.

6. The use of a fuel additive according to any one of the previous claims,
characterized in that
the fuel additive comprises a mixture of TBHP and tert-butyl alcohol (TBA).

7. The use of a fuel additive according to any one of the previous claims,
characterized in that
the diesel fuel without fuel additive has a cetane number of < 50.

8. The use of a fuel additive according to any one of the previous claims,
characterized in that
the diesel fuel with fuel additive has a cetane number larger by at least 2 compared to the diesel fuel without fuel additive.

9. The use of a fuel additive according to any one of the previous claims,
characterized in that
the diesel engine has a displacement of at least 1000 cm^3 per cylinder.

10. The use of a fuel additive according to any one of the previous claims,
characterized in that
the peroxide is used in an amount of 0.001 wt.% to 10 wt.% based on the total weight of the fuel.

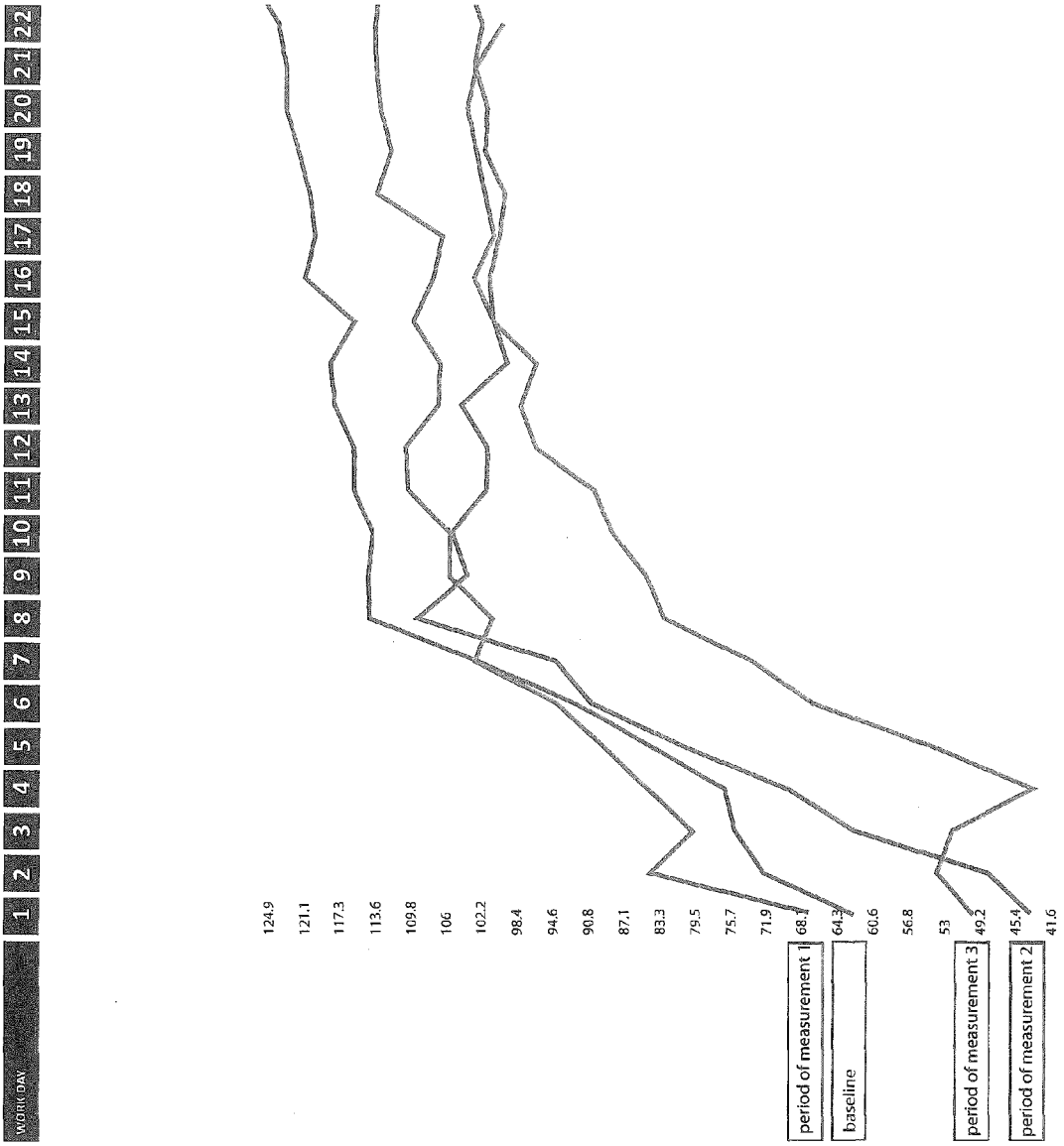
11. The use of a fuel additive according to any one of the previous claims,
characterized in that
the fuel consumption with fuel additive is reduced by at least 5 % compared to the fuel consumption without fuel additive.

12. The use of the fuel additive according to any one of the previous claims,
characterized in that
the fuel consumption is reduced when the fuel additive is continuously used for an operation time of the engine of at least 100 h.

13. The use of a fuel additive according to any one of the previous claims,
characterized in that
deposits in the engine are prevented, reduced and/or removed.

14. The use of the fuel additive according to any one of the previous claims,
characterized in that
the diesel fuel with a fuel additive has a HFRR score of at least 70 lower than the diesel fuel without a fuel additive.

Figure 1


WORKDAY
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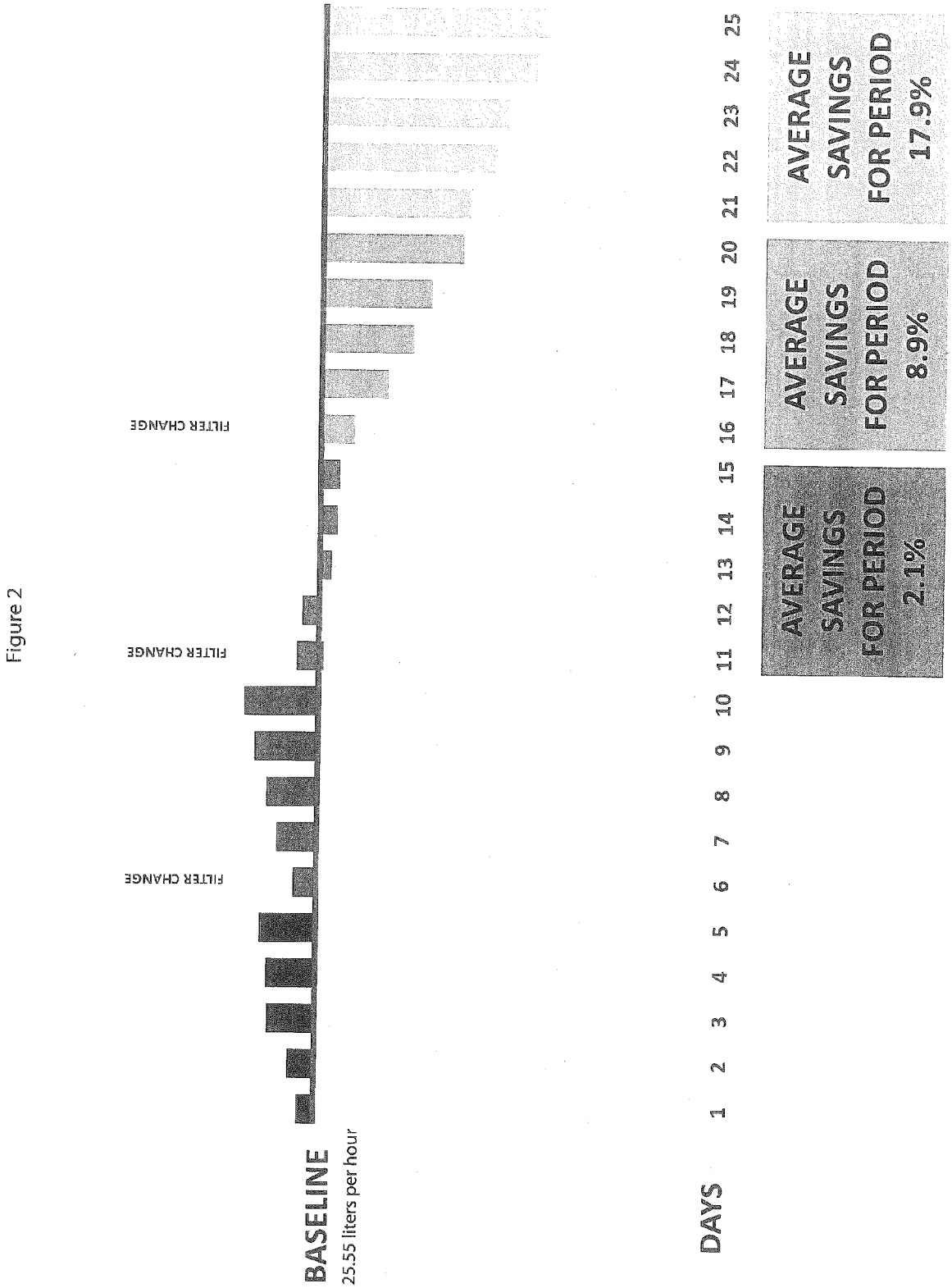
124.9
121.1
117.3
113.6
109.8
106
102.2
98.4
94.6
90.8
87.1
83.3
79.5
75.7
71.9
68.1
64.3
60.6
56.8
53
49.2
45.4
41.6
period of measurement 1
baseline
period of measurement 3
period of measurement 2

Figure 2


BASELINE
25.55 liters per hour
FILTER CHANGE
FILTER CHANGE
FILTER CHANGE
DAYS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
AVERAGE SAVINGS FOR PERIOD 2.1%
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AVERAGE SAVINGS FOR PERIOD 17.9%

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EUROPEAN SEARCH REPORT

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	8 October 2015	Bork, Ana-Maria

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EUROPEAN SEARCH REPORT

Application Number
EP 15 16 5433

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
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