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Research article

A new kind of pour point depressant: Diesel from direct coal liquefaction

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ABSTRACT

Coal liquefaction (CL) technology is a feasible solution to the energy crisis. The coal-to-liquid conversion includes direct CL (DCL) and indirect CL. Compared with the limited and unevenly distributed petroleum resources, the diesel from DCL (DDCL) has received worldwide attention since the beginning of this century and has been considered a substitute for diesel fuel. In this study, DDCL was regarded as a potential additive to improve the cold flow properties of petrodiesel. Other properties of the blending were also evaluated. When 40% DDCL was added to petrodiesel, the pour point (PP) reached −31 °C, and the cold filter plugging point (CFPP) reached −15 °C. The ΔPP and ΔCFPP decreased by 24 and 13 °C, respectively. The other properties, such as flash point and water content were not affected with the addition of DDCL. The cetane number of the blending were decreased but can be solved by adding fatty acid esters easily. The blending could be used in most climatic zones in the world, except the polar regions. In addition, Crystallization behavior was investigated via differential scanning calorimetry (DSC), and find that petrodiesel blended with 40% DDCL is more stable than blended with 10% and 20% DDCL.

1. Introduction

The rapid increase in crude oil consumption and the limited and unevenly distributed petroleum resource reserves in the world have worsened the energy crisis. Consequently, coal liquefaction (CL) technologies have received worldwide attention since the beginning of this century [1–3]. These technologies are a feasible solution to the global energy crisis because they utilize coal resources as fuel alternatives to petroleum. Coal resources are abundant in China. The coal-to-liquid technology is one of the most reasonable approaches for alternative liquid fuels and has been technically and commercially established [3]. This technology includes direct CL (DCL) and indirect CL.

As a project of national importance, the DCL project is of strategic significance to the national energy security and the structural adjustment of the primary energy mix of China [4]. This project constitutes a vital component of the Development Program for the Western Regions of China. Multi-stage liquefaction includes pretreatment, keeping the reactor at 250 °C for 40 min before heating up to the reaction temperature, and two-stage liquefaction processes that consist of low-temperature stage (400 °C) and high-temperature stage (460 °C) [5,6]. DCL has low-temperature properties, good oxidation stability, and low sulfur content.

Although CL has several disadvantages compared with petrodiesel, such as low cetane number, and high density, the diesel from DCL (DDCL) possess low temperature property that is beneficial when blending with diesel fuel.

The addition of DDCL does not require increasing the cost of diesel additives, implying that it has many advantages, such as being energy saving and its ease of use [6]. First, people can add different amount of DDCL according to the local temperature environment. Second, the properties of petroleum-based diesel and DDCL can complement each other. For example, adding petrodiesel can improve the low cetane number of DDCL and reduce its density. Adding DDCL to petrodiesel can also address the disadvantages of petrodiesel, such as improve its low-temperature properties and reduce its sulfur content. DDCL can balance the overall properties of petrodiesel. In this study, we successfully improved the low-temperature properties of petrodiesel with the addition of DDCL.

Petrodiesel is an important fuel derived from petroleum and mainly contains mixtures of hydrocarbon chains ranging from C8 to C30 [7,8]. Hydrocarbons are important to the transportation of diesel fuels and the operability of diesel engines. However, the solubility of hydrocarbon decreases easily at a low temperature [9]. Hydrocarbon chains segment toward one another because the van der Waals forces result in the formation of wax crystals [10,11]. When temperature decreases, paraffin crystals grow and create a crystalline net, thereby causing cold flow problems [12]. Global weather changes also cause dramatic climate changes. Heavy snowstorms have become normal in many parts of the world in recent years. Therefore, a method that can enable the use of petrodiesel in extremely cold weather should be determined.

Low temperature properties are characterized as the ability of a fuel to resist solidification at sub-ambient temperatures. The low temperature

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Table 1
Sample of DDCL and petrodiesel.

Properties	Density (kg/cm^3, 20 °C)	Kinematic viscosity (mm^2/s, 40 °C)	Flash point (°C)	CFPP[a] (°C)	Sulfur content (μg/g)	PP[b] (°C)	CN[c]	Water content (ppm)
Diesel	814	2.279	77	−2	310	−7	53	17
DDCL	860.1	2.02	75	−31	1.5	−53	44	50

[a] CFPP denotes cold filter plugging point.
[b] PP denotes pour point.
[c] CN denotes cetane number.

properties are usually determined by pour point (PP) and cold filter plugging point (CFPP). Several approaches have been studied to improve the low-temperature properties of petrodiesel. First, cold flow-improving additives or solvents have been added to petrodiesel [13–18]. This approach is the easiest and most feasible method to improve petrodiesel properties. Second, diesel has been blended with other kinds of fuel that possess good low-temperature properties [19,20]. Third, winterization has been conducted. However, this approach reduces the cetane number and has related effects on combustion and poor oxidation.

First, DDCL possess excellent low-temperature properties. Second, the other properties of DDCL have an equivalent performance to the majority of petrodiesel; hence, it may be regarded as a cold flow improver. DDCL also contains low sulfur. Nevertheless, the use of DDCL as a pour-point depressant has never been reported. The amount of DDCL can be adjusted according to the temperature of petrodiesel reduction.

In this research, we studied the effect of blending DDCL with petrodiesel on fuel characteristics. We also evaluated the effects of PP, CFPP, and sulfur content when the blending levels range from 0% to 40%. Several other properties that may affect the fuel performance in the engine, such as the density, viscosity, derived cetane number, and flash point, were investigated as well.

2. Experimental

2.1. Preparation of samples

DDCL was provided by the Shanghai Institute of China SH Coal to Liquid and Chemical Co., Ltd.

Diesel fuel was purchased from the market.

2.2. Measurement by gas chromatography–mass spectrometry (GC–MS)

Agilent 6890A-5973c GC–MS was used to analyze the composition of DDCL. The GC operation conditions are as follows: an HP-Innowax quartz capillary column (60 m × 0.25 mm × 0.25 μm) was used; the capillary column temperature was raised by 5 °C/min from 90 °C to 290 °C; the interface temperature was 280 °C; the injector temperature was 260 °C; the diffluent ratio was 100:1; a high-purity helium carrier was utilized; the gas flow rate was 1.2 mL/min (high-purity helium carrier); and the injection volume was 0.2 μL.

2.3. Measurement of CFPP and PP

PP and CFPP are important properties related to the low-temperature operability of diesel fuels [21–23]. PP is the temperature at which a fuel can no longer be poured due to gel formation, and CFPP is the lowest temperature tested where a specified volume of the fuel successfully filters through a specified wire-mesh filter within a specified period of time. In this study, PP and CFPP of the blending were measured on a low-temperature flow tester following the SH/T0248 procedures (SH/T0248 is a Chinese method for determining PP and CFPP.) [24].

2.4. Measurement of viscosity

The viscosity of the blending affects the low-temperature flow characteristics [25,26]. In this study, the kinematic viscosities of the blending at 40 °C were measured on a DRT-1102D rheometer (Qing yang Dairuite

Table 2
Compounds detected in DDCL.

Peak	Compound	RC, %	Peak	Compound	RC, %
1	Propylcyclohexane	1.78	26	1,1-Dicyclopentylethane	0.84
2	*trans*-Hexahydroindane	1.63	27	1-Pentyl-1-cyclohexene	0.91
3	1-Cyclopentylethyl dichloroacetate	0.52	28	Undecane	3.44
4	1-Acetyl-1-methylcyclohexane	1.36	29	2-Methyldecahydronaphthalene	10.47
5	*cis*-Hexahydroindane	4.64	30	1-Methyldecahydronaphthalene	3.80
6	Propan-2-ylidenecyclohexane	0.92	31	Octylcyclohexane	2.90
7	1,2-Diethylcyclohexane	0.56	32	Pentylcyclohexane	1.04
8	Decane	2.79	33	Dihydrocarvone	1.13
9	Hexahydro-5-methylindane	1.57	34	1-Methyl-1-cyclodecene	1.23
10	1-Isopropyl-4-methylcyclohexene	0.67	35	2,6-Dimethyldecalin	1.14
11	(Isobut-1-enyl)cyclohexane	1.15	36	1,5-Dimethyldecahydronaphthalene	0.60
12	2,6-Dimethylbicyclo[3.2.1]octane	0.74	37	Dodecane	2.65
13	Butylcyclohexane	2.37	38	2-Ethyldecalin	2.11
14	1-Butyl-1-cyclohexene	3.04	39	(Cyclopentylmethyl)cyclohexane	1.00
15	1-Isopropyl-4-methylcyclohexane	1.24	40	1,1′-Bicyclohexyl	1.14
16	Iridomyrmecin	1.06	41	Tridecane	2.40
17	5-Isopropyl-1,4-dimethyl-1-cyclopentene	0.84	42	2-Ethyldecahydronaphthalene	1.00
18	Decahydronaphthalene	16.91	43	Dodecahydro-1H-phenalene	1.95
19	*cis*-Decahydronaphthalene	1.29	44	3-Cyclohexyl-1-propanol	0.86
20	3-Pentyl-1-cyclohexene	1.47	45	7-Octylidenebicyclo[4.1.0]heptane	0.65
21	1-Isopropyl-1-methylcyclohexane	0.60	46	Perhydroanthracene	0.64
22	(1,2-Dimethylcyclopentyl)methanol	1.30	47	Tetradecane	2.19
23	3-(Isopropyl)-6-methylcyclohex-2-*en*-1-one	0.85	48	2-*n*-Butyldecahydronaphthalene	0.88
24	1-Ethyl-2-propylcyclohexane	0.78	49	Hexadecane	1.4
25	*cis*-Decalin	2.79	50	Nonadecane	0.78