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Direct synthesis of a high-density aviation fuel using a polycarbonate†

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High-density cyclic hydrocarbons were first synthesized with high carbon yields by a one-pot transfer hydrodeoxygenation of a polycarbonate (PC) using isopropanol as the solvent and hydrogen donor at the same time. RANEY® nickel was found to be an effective catalyst for the conversion of the PC in isopropanol. Over it, the pure PC pellet was completely converted to a mixture of C_6–C_{15} oxygenates, aromatics and cycloalkanes after the reaction was carried out at 463 K for 1 h. The catalytic performance of RANEY® Ni was further improved after the introduction of solid acids as co-catalysts. Among the investigated solid acids, ultrastable Y (USY), a commercial acidic zeolite, demonstrated the best promotion effect, which can be explained by its larger pore size and suitable acidity. Under the optimized conditions, an ~75% carbon yield of C_6–C_{15} cyclic hydrocarbons was achieved from the one-pot transfer hydrodeoxygenation of a chopped DVD disk under the co-catalysis of RANEY® Ni and USY. According to our measurement, the C_6–C_{15} cyclic hydrocarbon mixture as obtained has a high density (0.94 g mL^{-1}), good volumetric net heat of combustion (NHOC) (41.5 MJ L^{-1}) and low freezing point (202 K–188 K). In real applications, it can be used as a potential substitute for currently used high-density aviation fuels.

Introduction

Due to the increasing social concerns about energy and environmental problems, the recycling of waste plastic as a feedstock to produce fuels and chemicals has drawn tremendous attention.[1] Polycarbonates (PCs) are a type of hard plastic which have been widely used in construction, electric, automotive, commodity and medical industries.[2] The annual global polycarbonate productivity was estimated to be ~6 million tons.[3] Furthermore, the demand for PCs is continuously increasing in recent years. This will lead to plenty of PC waste in the near future. To fulfil the need for sustainable development, it is necessary to develop some environmentally friendly and highly efficient technologies for the recycling of PCs. During the past years, a series of methods (including pyrolysis,[4] hydrolysis,[5] alcoholysis,[3,6] glycolysis[7] and aminolysis[8]) have been applied for PC waste recycling. Transfer hydrodeoxygenation is a technology that has been widely used for the production of fuels[9] and chemicals.[10,11] Compared with the conventional hydrodeoxygenation that uses hydrogen as the reactant, transfer hydrodeoxygenation is relatively safe and easier to handle.[12] To the best of our knowledge, there is no report about the application of transfer hydrodeoxygenation in the treatment of PC waste.

High-density cyclic hydrocarbons are the major components of nontoxic propellants (such as RP-1, RJ-4 and JP-10), which are widely utilized for rockets and missiles.[13,14] Due to their relatively high volumetric heat values, the aerocrafts that use cyclic hydrocarbons as fuels can fly further or carry more than those powered by conventional aviation fuels. This characteristic can help rockets save more space (or weight) for electronic equipment, astronauts and other components. Moreover, this characteristic can also be used to decrease the volume or radar reflection area and make missiles more agile and difficult to be detected by the opposing side. Currently, RP-1 fuel and its analogues are obtained from the refinement of petroleum in few special oil fields. RJ-4 and JP-10 fuels are produced with cyclopentadiene or methyl-cyclopentadiene, which are obtained in very low yields from fossil energies (for example, cyclopentadiene is produced from coal tar in a yield of 10–20 g per ton or by steam cracking of naphtha in a yield

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of 14 kg per ton).[15] The yield of methyl-cyclopentadiene is even lower[16]. As a result, these fuels are more expensive than pure PCs. To fulfil the need for real applications, the exploration of a new route for the synthesis of high-density aviation fuels with abundant resources is highly expected. In this work, a mixture of jet fuel range C_6–C_{15} cycloalkanes and aromatics was first synthesized by the RANEY® Ni and USY co-catalysed one-pot transfer hydrodeoxygenation of PCs using isopropanol as the hydrogen donor and solvent at the same time. This work offers another potential way for the reuse of PC waste.

Experimental

Materials and methods

In this work, pure poly[2,2-bis(4-hydroxyphenyl)propane carbonate] (PC) pellets (product number: 1609T-11, 2 mm length × 2 mm diameter) from Luxi Chemical Group Co., Ltd were used to simulate the PC waste. According to the analysis using a Waters 1525 & Agilent PL-GPC220 gel permeation chromatography (GPC) system and an X-5 micro melting point apparatus (Beijing Tech Instrument Co. Ltd), the average molecular weight and melting point of the pure PC pellets were found to be 36 226 and 456 K–461 K, respectively. Based on thermogravimetric-differential scanning calorimetry (TG-DSC) (see Fig. S1 in the ESI†), the decomposition temperature of the PC was found to be 718 K. To check the possibility of real application, we also used a chopped DVD disk (a representative of real PC waste) as the substrate for the activity test. Before the test, the DVD disk was cut into 2 mm × 2 mm pieces with scissors. RANEY® Ni, RANEY® Fe, RANEY® Co and RANEY® Cu were bought from Dalian Tongyong Chemical Co., Ltd. Methanol, isopropanol, cyclohexanol, phenol and ethylbenzene were purchased from Damao Chemical Reagent Factory. 2-Butanol, ethanol and Al_2O_3 were purchased from Sinopharm Chemical Reagent Co., Ltd. Diphenyl carbonate and *n*-dodecane (used as the internal standard in this work) were obtained from Aladdin Chemical Reagent Co., Ltd. The H-ZSM-5 and USY zeolites were purchased from Nankai University. According to the information from the supplier, the SiO_2/Al_2O_3 molar ratios of the H-ZSM-5 and USY zeolites were 25 and 11, respectively.

Characterization

The specific BET surface areas and pore sizes of the solid acids used as co-catalysts in the one-pot transfer hydrodeoxygenation were determined by N_2-physisorption at 77 K using a Micromeritics ASAP 2010 apparatus.

The acid amounts and acid strengths of the solid acids were characterized by NH_3-chemisorption and NH_3-TPD, respectively. Before each test, 0.1 g sample was placed in a quartz reactor, pre-treated under a He flow at 773 K for 0.5 h and cooled down under a He flow to 373 K. After the stabilization of the baseline, pulses of NH_3 (1 mL) were dosed in the reactor until saturation. The number of acid sites on the catalyst was calculated using the adsorptions of NH_3 during the test. Subsequently, the desorption of NH_3 was conducted under a He flow from 373 K to 1073 K at a heating rate of 10 K min^{-1}. The desorbed NH_3 molecules were detected using an OminiStar mass spectrometry (MS) system equipped with the software Quadstar.

Activity tests

Transfer hydrodeoxygenation of PCs. The transfer hydrodeoxygenation of pure PC pellets was carried out in a 100 mL stainless steel batch reactor (Parr 4848) under an argon atmosphere. For each test, 2 g of pure PC pellets and 45 mL of alcohol were used. After purging the reactor three times with argon, the mixture was stirred at 443 K–523 K for 1 h.

One-pot transfer hydrodeoxygenation. The one-pot transfer hydrodeoxygenation of pure PC pellets (or the chopped DVD disk) was carried out in a 100 mL stainless steel batch reactor (Parr 4848) under an argon atmosphere. For each test, 2 g of pure PC pellets (or the chopped DVD disk) and 45 mL of isopropanol were used. After purging the reactor three times with argon, the mixture was stirred at 463 K for 1 h, and then quenched to room temperature with cold water. Subsequently, 0.2 g of solid acid was added into the reaction system. After purging the reactor three times with argon, the reaction was carried out at 463 K for another 1–5 h.

Based on our observation, the operating pressures for the transfer hydrodeoxygenation (or one-pot transfer hydrodeoxygenation) were around 3 MPa under the investigated conditions. After the activity tests, the reactor was quenched to room temperature with cold water. The products were analyzed using an Agilent 7890A Gas Chromatography (GC) system, which was equipped with an HP-5 capillary column (30 m × 0.32 mm × 0.32 μm) and a flame ionization detector (FID) and an Agilent 7890B-5977A gas chromatography-mass spectrometry (GC-MS) system which was equipped with an HP-5 capillary column. To minimize the vaporization of C_6 cyclic hydrocarbons, the products were analysed within 1 h after they were taken out from the batch reactor.

The PC conversions and the carbon yields of oxygenates and cyclic hydrocarbons from the transfer hydrodeoxygenation (or one-pot transfer hydrodeoxygenation) were calculated according to the following equations:

$$\text{Conversion of PC}\ (\%) = (\text{initial weight of pure PC pellets(or chopped DVD disk)} - \text{the weight of residual PC pellets (or residual chopped DVD disk)})/(\text{initial weight of pure PC pellets (or chopped DVD disk)}) \times 100\%.$$

$$\text{Carbonyield of oxygenates or cyclic hydrocarbons}\ (\%) = (\text{mole of carbon atoms in the oxygenates or cyclic hydrocarbons generated during the activity test})/(\text{theoretical mole of carbon atoms in the PC (or chopped DVD disk) used in the activity test}) \times 100\%.$$

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Isopropanol and acetone have low boiling points (355.5 K and 329.4 K). After their removal of from the one-pot transfer hydrodeoxygenation product of the chopped DVD disk by vacuum distillation, a mixture of C_6–C_{15} cyclic hydrocarbons was obtained. The boiling point distribution of the cyclic hydrocarbon mixture was analyzed by simulated distillation using the ASTM D2887 method. The viscosity, density, freezing point and net heat of combustion (NHOC) of the C_6–C_{15} cyclic hydrocarbon mixture were measured using a rotational rheometer (Physica MCR 301), a DMA 4500 M digital densitometer, a NETZSCH DSC 200F3 and a TP638 calorimeter (ASTM D240-02), respectively.

Results and discussion

First of all, a series of RANEY metals were found to be effective catalysts for the degradation of pure PC pellets (denoted as PC in the following text) in isopropanol. As we can see from Fig. 1, isopropanol has low reactivity for the degradation of PC. Under the investigated conditions, low PC conversion (or C_6–C_{15} oxygenate yield) was obtained. It is interesting that the presence of RANEY metal significantly promoted the degradation of PC. Over them, evidently higher PC conversions were achieved under the same reaction conditions. For example, the PC was completely converted over the RANEY® Ni catalyst after the reaction was carried out at 463 K for 1 h. Even over the RANEY® Co, RANEY® Cu and RANEY® Fe catalysts (which are less effective than RANEY® Ni under the investigated conditions), good results were achieved with further increment of the catalyst dosage (see Fig. 1, Table S1 and Fig. S2–S4 in the ESI†).

Based on our analysis of liquid phase products (see Fig. S5 in the ESI†), bisphenol A and 4-(2-(4-hydroxyphenyl)propan-2-yl)phenyl isopropyl carbonate were obtained as the products when the reaction was carried out in the absence of a catalyst. These products were generated from the alcoholysis of PC. In the presence of the RANEY® Ni catalyst, a series of C_6–C_{15} oxygenates (including cycloalcohols, diols and phenols) and cyclic hydrocarbons (including cycloalkanes and aromatics) were obtained as the main products. The reaction pathways for the generation of different products were proposed as shown in Scheme 1. According to Table S2 in the ESI,† the C_6–C_{15} cyclic hydrocarbons obtained in this work have high densities. In real applications, the cyclic hydrocarbon mixture as obtained can be potentially used as a high-density aviation fuel. Meanwhile, we also analyzed the gas phase products from the transfer hydrodeoxygenation of PC. Based on the GC chromatogram shown in Fig. S6 in the ESI,† hydrogen, methane and carbon dioxide were detected. Hydrogen was produced from the dehydrogenation of isopropanol, carbon dioxide was generated from the hydrolysis of PC, while methane was generated from the hydrogenolysis of the carbonate group in PC.

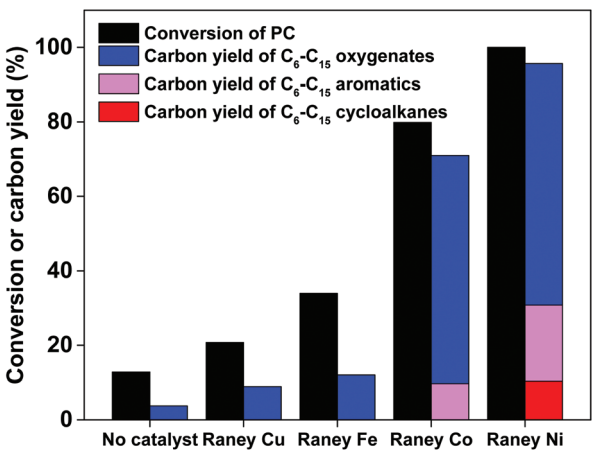

Fig. 1 Conversions of PC and the carbon yields of C_6–C_{15} oxygenates and cyclic hydrocarbons over different RANEY metal catalysts. Reaction conditions: 463 K, 1 h; 2 g of pure PC pellets, 0.4 g of catalyst and 45 mL of isopropanol were used in each test.

Taking RANEY® Ni as an example, we investigated the effects of different alcohols on its catalytic performance for the transfer hydrodeoxygenation of PC (see Fig. 2). Among the investigated alcohols, isopropanol exhibited the highest reactivity for the degradation of PC. The reactivities of different alcohols decreased in the order of isopropanol > 2-butanol > methanol > ethanol. From the analysis of products (see Fig. S7 in the ESI†), a strong dependence was noticed between the product distribution and the type of alcohol used in the reaction. When the degradation was carried out in primary alcohols (such as methanol and ethanol), bisphenol A and carbonates from the alcoholysis of PC were obtained. In contrast, alcohols, diols and hydrocarbons were obtained when the reaction was conducted in secondary alcohols (such as isopropanol and 2-butanol). According to the literature on the transfer hydrogenation of phenol,[10] this result can be explained by the adsorption mode of the intermediate. When the reaction was carried out in primary alcohols, the alkoxy groups generated by the cleavage of the O–H bond may block the metal surface and make it inactive for the subsequent transfer hydrogenation (or transfer hydrodeoxygenation). In contrast, the Ni catalyst was unblocked in isopropanol (or 2-butanol) because the O–H and α-C–H bonds were cleaved at the same time. This is the reason why transfer hydrodeoxygenation can take place in secondary alcohols. Therefore, we concentrated on the degradation of PC over RANEY® Ni using isopropanol as a hydrogen donor in the following research.

The influences of the reaction time and temperature on the catalytic performance of RANEY® Ni were also studied. As we can see from Fig. 3, the total carbon yield of cyclic hydrocarbons over the RANEY® Ni catalyst firstly increased with the reaction time and then stabilized after 1 h. Further increment of the reaction time only led to the increase of the cycloalkane carbon yield and the decrease of the aromatic carbon yield at the same time. This result indicates that at least one part of cycloalkanes in the product may be generated by the transfer hydrogenation of C_6–C_{15} aromatics.

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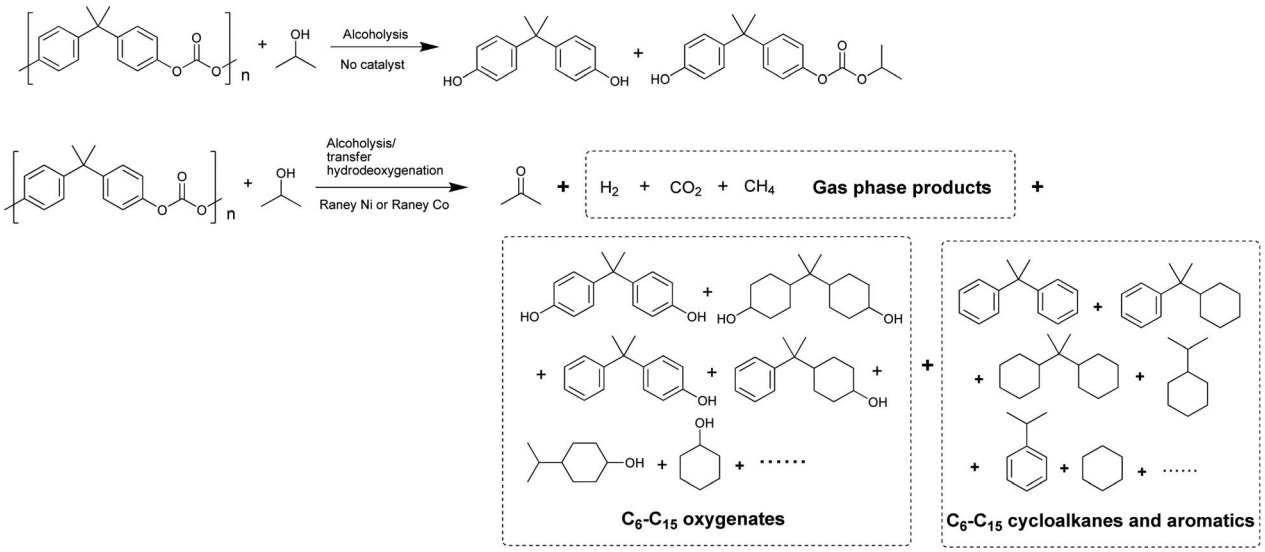

Scheme 1 Reaction pathways for the generation of different products from the degradation of PC in isopropanol.

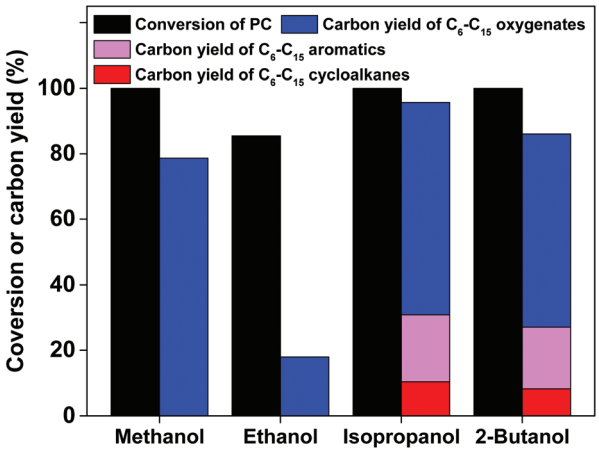

Fig. 2 Conversions of PC and the carbon yields of C_6–C_{15} oxygenates and cyclic hydrocarbons over the RANEY® Ni catalyst. Reaction conditions: 463 K, 1 h; 2 g of pure PC pellets, 0.4 g of RANEY® Ni catalyst and 45 mL of alcohol were used in each test.

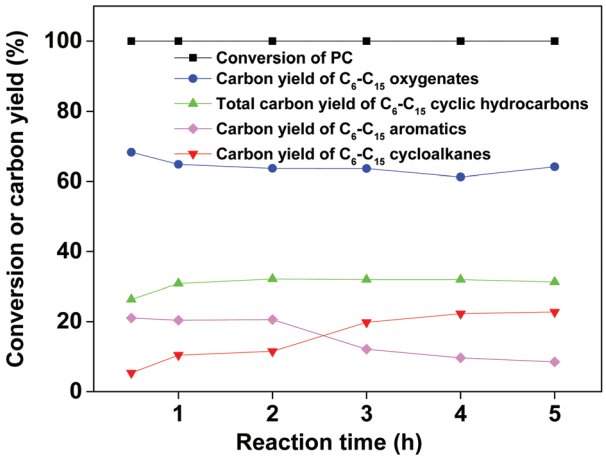

Fig. 3 Conversions of PC and the carbon yields of C_6–C_{15} oxygenates and cyclic hydrocarbons over the RANEY® Ni catalyst as a function of the reaction time. Reaction conditions: 463 K; 2 g of pure PC pellets, 0.4 g of RANEY® Ni and 45 mL of isopropanol were used in each test.

From Fig. 4a, it is noticed that a higher reaction temperature is favorable for the conversion of PC into cyclic hydrocarbons (especially cycloalkanes). This can be comprehended because the dehydrogenation of isopropanol is an endothermic reaction. However, the beneficial effect resulting from raising the reaction temperature is limited. After we increased the reaction temperature from 463 K to 523 K, the total carbon yield of C_6–C_{15} cyclic hydrocarbons only increased from 31.0% to 44.7%. Furthermore, a too high reaction temperature also led to hydrocracking, which can be indicated by the higher molar ratio of C_6 and C_9 products to C_{15} products (see Fig. 4b and Fig. S8 in the ESI†). As we can see from Table S2 in the ESI,† the monocyclic hydrocarbons generated by hydrocracking at a high temperature have lower densities than those of dicyclic hydrocarbons. Therefore, we fixed the reaction temperature at 463 K in the following research.

To get an idea about how to improve the performance of the catalyst, we explored the transfer hydrodeoxygenation (or transfer hydrogenation) of a series of model compounds over the RANEY® Ni catalyst. First, we studied the reaction of diphenyl carbonate, a good model compound which has a chemical structure similar to PC. Under the standard reaction conditions as we used for pure PC pellets, cyclohexane and cyclohexanol were obtained as the products (see Fig. 5 and Fig. S9 in the ESI†). From Scheme 2, we can see that cyclohexanol was generated from the transfer hydrogenation of phenol (*i.e.* the alcoholysis product of diphenyl carbonate). As for the generation of cyclohexane, there are two pathways: one is the

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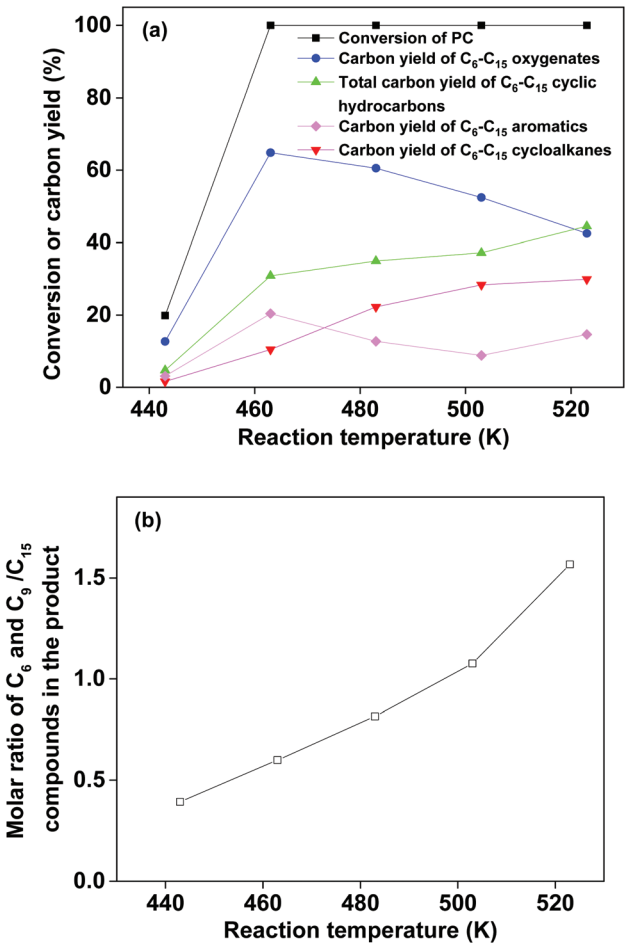


Fig. 4 Conversions of PC, the carbon yields of C_6–C_{15} oxygenates and cyclic hydrocarbons over the RANEY® Ni catalyst (a) and the molar ratio of C_6 and C_9/C_{15} compounds in the transfer hydrodeoxygenation product (b) as a function of the reaction temperature. Reaction conditions: 1 h; 2 g of pure PC pellets, 0.4 g of RANEY® Ni and 45 mL of isopropanol were used in each test.

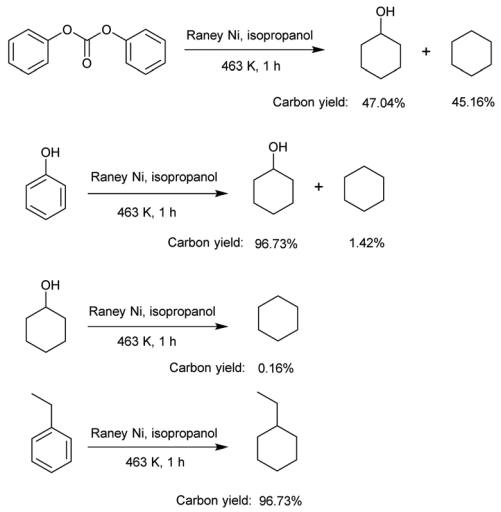
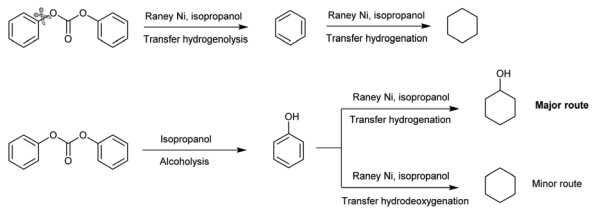


Fig. 5 Carbon yields of different products from the transfer hydrodeoxygenation of model compounds over the RANEY® Ni catalyst. Reaction conditions: 463 K, 1 h; 8 mmol of the model compound and 45 mL of isopropanol were used in each test.



Scheme 2 Reaction pathways for the generation of cyclohexane and cyclohexanol from the transfer hydrodeoxygenation of diphenyl carbonate.

hydrogenation of benzene from the hydrogenolysis of diphenyl carbonate (by the direct cleavage of the C–O bond between the benzene ring and ester group) and the other is the transfer hydrodeoxygenation of phenol or cyclohexanol generated from the alcoholysis route. To check which pathway is correct, we studied the reaction of phenol and cyclohexanol under the standard conditions. It was noticed that the conversion of phenol (or cyclohexanol) to cyclohexane was very difficult. Low yields of cyclohexane were obtained. When we used phenol and ethylbenzene as the substrates, cyclohexanol and ethylcyclohexane were identified as the major products, respectively. Therefore, we believe that the cyclohexane from the transfer hydrodeoxygenation of diphenyl carbonate was mainly generated by the direct cleavage of the C–O bond between the benzene ring and ester group.

Based on the mechanism research about the transfer hydrodeoxygenation of diphenyl carbonate, we can see that the transfer hydrogenation of the benzene ring group in aromatics (or phenol) to cycloalkane (or cyclohexanol) is an easy reaction over RANEY® Ni, while the transfer hydrodeoxygenation (or C–O cleavage) of phenol or cyclohexanol is difficult to occur over RANEY® Ni under the investigated conditions. The increase of the reaction temperature is beneficial for the dehydrogenation of isopropanol and the hydrogenolysis of the C–O bond over RANEY® Ni. As a result, a higher total carbon yield of hydrocarbons was obtained with the increment of the reaction temperature. However, the increment of the reaction temperature also promotes the hydrogenolysis of the C–C bond (or the production of monocyclic hydrocarbons) over the RANEY® Ni catalyst. Moreover, the transfer hydrogenolysis and alcoholysis of carbonate take place in parallel under the investigated conditions. The generation of cyclic hydrocarbons from the transfer hydrodeoxygenation of phenols (or cycloalcohols) is difficult under the investigated conditions. That is the reason why the beneficial effect of the high reaction temperature is limited.

As a solution to this problem, we developed a one-pot process that contains two steps. In the first step, the PC was degraded in isopropanol using RANEY® Ni as the catalyst. After reacting at 463 K for 1 h, the reaction system was cooled down to room temperature. Subsequently, a solid acid was

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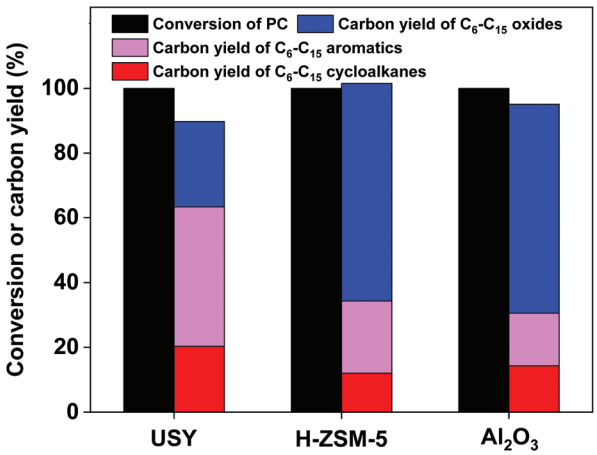

Fig. 6 Conversions of PC and the carbon yields of C_6–C_{15} oxygenates and cyclic hydrocarbons under the co-catalysis of RANEY® Ni and different solid acids. Reaction conditions: 463 K, 1 h; 2 g of pure PC pellets, 0.2 g of solid acid, 0.4 g of RANEY® Ni and 45 mL of isopropanol were used in each test.

introduced into the reaction system, and the reaction was conducted at 463 K for another 1 h. Fig. 6 illustrates the PC conversions and the carbon yields of C_6–C_{15} cyclic hydrocarbons from the one-pot process under the co-catalysis of RANEY® Ni and some often-used solid acids. As we expected, the presence of solid acid increased the total carbon yield of C_6–C_{15} hydrocarbons from the transfer hydrodeoxygenation of PC. Among the investigated solid acids, USY demonstrated the best promotion effect. In the presence of USY, the products shifted from oxygenates to cyclic hydrocarbons (see Fig. 7 and Fig. S10 and S11 in the ESI†).

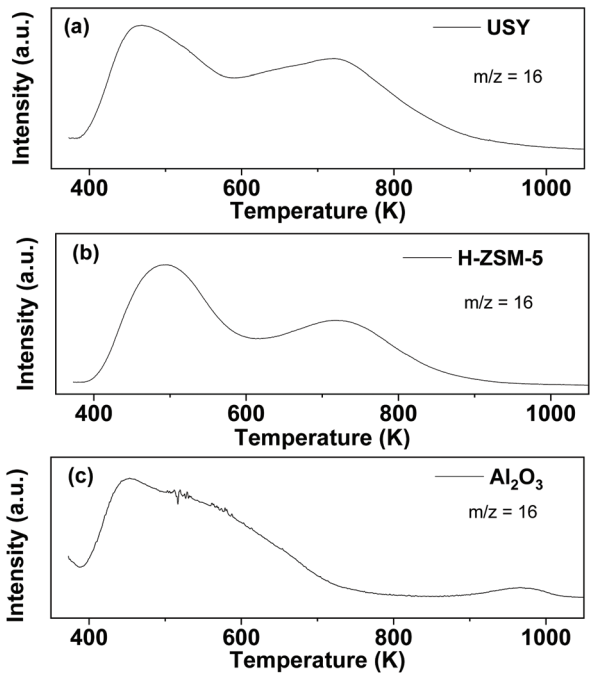

Fig. 7 NH_3-TPD profiles of USY, H-ZSM-5 and Al_2O_3.

Table 1 Specific surface areas (S_{BET}), acid amounts and pore sizes of the solid acids used in this work

Solid acid	S_{BET} [a] ($m^2\ g^{-1}$)	Acid amount [b] (mmol g^{-1})	Pore size (nm)	Ref.
USY	657	0.880	0.74 × 0.74 [c]	17
H-ZSM-5	328	0.975	0.51 × 0.55 0.53 × 0.56 [c]	17
Al_2O_3	204	0.430	8.9 [a]	—

[a] Measured by N_2-physisorption. [b] Measured by NH_3-chemisorption. [c] The values are reported in the literature.

According to the characterization results (see Fig. 7 and Table 1), the excellent promotion effect of USY can be explained by two reasons: (1) larger pore size. This is because the Y zeolite (IZA structure, FAU type) is characterized by large, essentially spherical, internal cavities (supercages) linked tetrahedrally through pore openings of about 0.8 nm and defined by rings of twelve oxygen atoms. As we know, the mass transfer is very important for the liquid phase reaction at low temperature. This is the reason why USY has a better promotion effect than that of H-ZSM-5. (2) Suitable acidity. As we can see from the NH_3-TPD profiles of different solid acids (see Fig. 7), USY has a higher acid strength than that of Al_2O_3. It is well known that a strong acid is more active than a weak acid for dehydration. Dehydration followed by hydrogenation is an important pathway for hydrodeoxygenation.[18] Due to these two reasons, USY has a better promotion effect than that of Al_2O_3.

The effect of the reaction time on the catalytic performance of RANEY® Ni + USY was investigated as well (Fig. 8). With the extension of the reaction time of the second step to 3 h, an ~80% total carbon yield of cyclic hydrocarbons was achieved under the co-catalysis of RANEY® Ni and USY.

To fulfil the need for real application, we also studied the catalytic performance of the RANEY® Ni + USY catalyst for the production of cyclic hydrocarbons with the chopped DVD disk

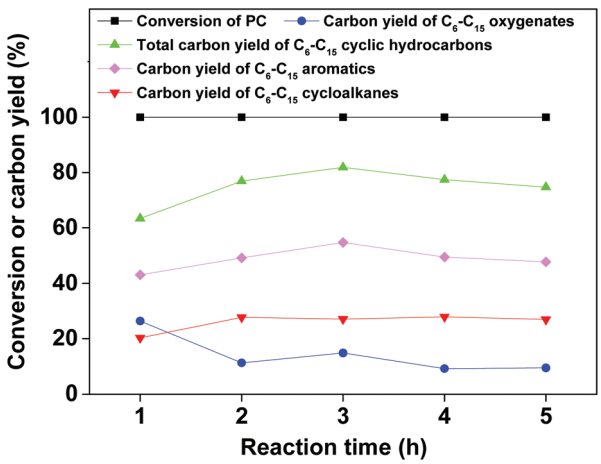

Fig. 8 Conversions of PC and the carbon yield of C_6–C_{15} oxides and cyclic hydrocarbons as a function of the reaction time. Reaction conditions: 463 K; 2 g of pure PC pellets, 0.2 g of USY, 0.4 g of RANEY® Ni and 45 mL of isopropanol were used in each test.

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Table 2 Properties of the currently used classic high-density aviation fuels and the cyclic hydrocarbon mixture obtained in this work

Property	RP-1[19]	RJ-4[14]	JP-10[14]	DVD disk derived fuel
Density (g mL^{-1})	0.81	0.927	0.936	0.939
Freezing point (K)	225	<233	194	202–188[b]
Viscosity (mPa s) (at 298 K)	2.4	—[a]	3.2	18.5
NHOC (MJ kg^{-1})	43.9	39.0	42.1	44.2
Volumetric NHOC (MJ L^{-1})	35.6	36.2	39.4	41.5

[a] Not available. [b] The boiling point distribution and DSC profile of the cyclic hydrocarbon mixture are shown in Fig. S12 and S13 in the ESI.†

which can be considered as a representative of real PC waste. As we expected, a high total carbon yield (75%) of C_6–C_{15} cyclic hydrocarbons was achieved under the optimized conditions for pure PC pellets. Based on this result, it is estimated that 3.68 tons of C_6–C_{15} cyclic hydrocarbons can be produced if 6 million tons of PC waste was converted by this technology.

As we know, acetone and isopropanol have low boiling points (329.4 K and 355.5 K). After their removal from the product by vacuum distillation, we measured the properties of the cyclic hydrocarbon mixture by a series of technologies. From the results presented in Table 2, we can see that the cyclic hydrocarbon mixture obtained from the one-pot transfer hydrodeoxygenation of the chopped DVD disk has better properties than those of RP-1 and RJ-4. Its density, volumetric heat value and freezing point are comparable to those of JP-10, the most successfully used high-density aviation fuel. The only disadvantage of the cyclic hydrocarbon mixture is its relatively high viscosity. In real applications, this problem can be solved by blending it with current bio-jet fuels (*i.e.* mixtures of biomass derived low-freezing point synthetic paraffinic kerosenes), which can make the process even greener. As we have mentioned previously in the Introduction, JP-10 fuel has a much higher price than that of pure PC (~7000 USD per ton *vs.* ~2000 USD per ton),[20] which means our process should be economically feasible in future applications.

Conclusions

A high-density cyclic hydrocarbon aviation fuel was first synthesized with a high carbon yield by a one-pot transfer hydrodeoxygenation of PC. RANEY® Ni, a commercial metal catalyst, was found to be effective for the degradation of PC. The promotion effect of RANEY® Ni was more evident when we used isopropanol as the hydrogen resource. The catalytic performance of RANEY® Ni was further improved by adding USY as a co-catalyst. Under the optimized conditions, ~75% total carbon yields of C_6–C_{15} aromatics and cycloalkanes were achieved from the transfer hydrodeoxygenation of a chopped DVD disk under the co-catalysis of RANEY® Ni and USY. The C_6–C_{15} cyclic hydrocarbon mixture as obtained has excellent properties (such as high density, good volumetric heat value and low freezing point). Therefore, it can be considered as a substitute for the currently used high-density aviation fuels. This work offers a new option for the recycling of PC waste.

Conflicts of interest

There are no conflicts to declare.

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