Novel Recycling Routes of Waste Poly(ethylene terephthalate) and Poly(carbonate) to Monomers

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Introduction

Development of technology in the 20th century has created many problems behind its positive faces. Among them are three crucial ones, i.e., global as well as local increase in environmental destruction, sky-rocketing consumption of energy, and shortage of natural resources particularly of petroleum. These problems seem not to be solved before the 21st century and would become even more serious by the lack of consciousness among industrial, political and scientific leaders who are still biased toward short-term economical monetary benefit. Along this line, the petroleum resource will be depleted sooner or later disabling sustainable continuation of our society.

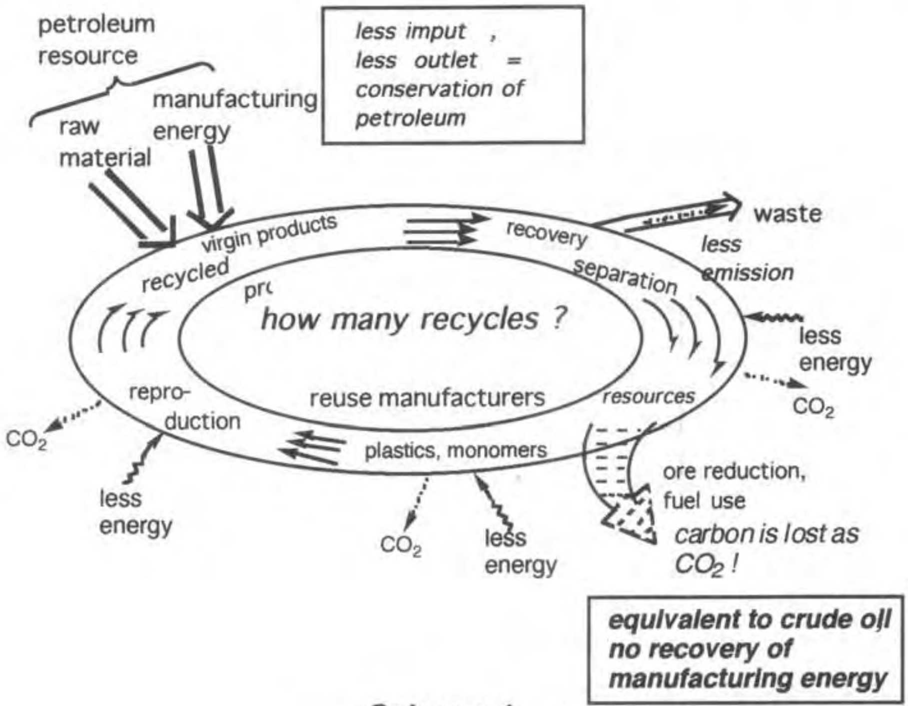
Depletion of petroleum resource is an inevitable fate of chemical industry. Plastics are made from petroleum the lifetime of which is estimated to be 30-60 years. Petroleum is not reproducible but plastics are reproducible by recycling the waste plastics.

Can we find an answer to this depletion problem during the next few decades ? There seems to be no answer unless we abandon the present one-sided and short-sighted chase of profit. We should never stop our efforts of reducing petroleum consumption by automobiles, electricity power plants, excessive production and consumption including chemical manufacturing, for the benefit of our descending generation.

Basic concept of the study

The question how to solve the plastic recycling problems in both post-manufacturer and post-consumer stages is now becoming one of the most important issues concerning the global conservation of organic and energy resources. In most developed countries, the major methods employed politically as the tool of solving this problem are generation of electricity, substitute for coke in ore reduction, and liquefaction to fuel oil. However, these methods are clearly incapable of solving the depletion problem of the petroleum resource on the earth [1, 2]. Nevertheless, these methods are capped with the key words "green" and "recycling" and overwhelming the issue of waste plastics. Against such deplorable worldwide trends as treating waste plastics as refuge but not recyclable plastic resources, we proposed that the recycling of plastics by means of retro-polymerization to monomers can be the primary solution of this problem. The reason is clear: retro-polymerization, in other words, monomer recycling method or chemical recycling method, is the most appropriate because (1) it can reproduce virgin-equivalent plastics repeatedly and (2) it can save both the petroleum resource and manufacturing energy (Scheme 1).

Thus, our study bases on the following concepts. (1) Commodity plastics must be recycled rather than creating a new type of recyclable polymers. (2) To save the energy of monomer production from crude oil, the retro-polymerization method should consist of simple technologies, i.e. low technologies. (3) Monomer reproduction facilities should

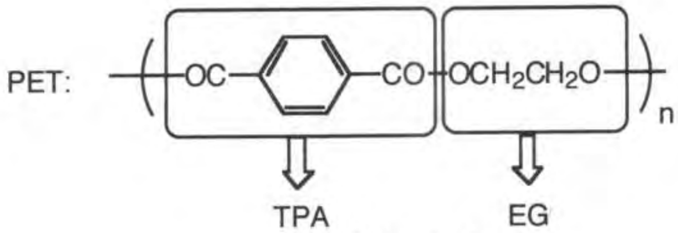


Scheme 1

be compact, inexpensive and of safe operation so that waste plastics are treated at local stations to reduce bulky wastes to less bulky monomers so that they can be efficiently transported to chemical industries. On this basic concept, we have studied the "chemical recycling"[3] of waste plastics of poly(ethylene terephthalate) (PET)[4, 5] and bisphenol-A polycarbonate (PC)[6] by conventional and low-energy consuming methods using simple industrial equipment.

Results and discussion

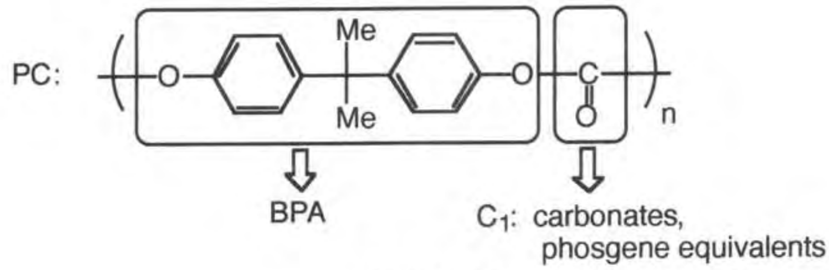
1. Retro-polymerization of PET to TPA and EG. Poly(ethylene terephthalate) (PET) is composed of terephthalic acid (TPA) and ethyleneglycol (EG). Our method is unique of using



Scheme 2

EG as the solvent (solvent-less process ?) under anhydrous conditions, and PET can be retro-polymerized quantitatively to pure TPA and EG even in the presence of colorants, plastic labels, caps and metals (Scheme 2).

2. Retro-polymerization of PC to BPA and dimethyl carbonate (DMC). Poly(carbonate) (PC) is composed of bisphenol A (BPA) and carbonic acid (C_1) (Scheme 3) and PC plastic goods are mostly made of PC, composite materials, plasticizers, laminated materials and colorants. They are removed by our catalytic retro-polymerization of PC to reproduce pure BPA and dimethyl carbonate (DMC), efficiently.



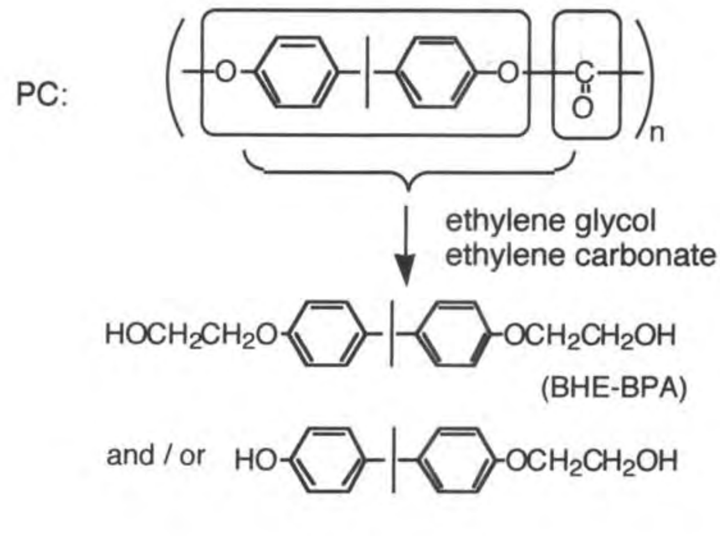
Scheme 3

3. Chemical transformation of PC to industrial chemicals.

It should also be noted that the two component units of PC, i.e., bisphenol-A (BPA) and carbon monoxide, are important industrial chemicals. In this concern, PC can be regarded as a chemical reagent equivalent to BPA and phosgene-equivalent as shown in Scheme 4. As an example, the chemical conversion of PC to bis(hydroxyethyl) ether of BPA (BHE-BPA), which is used as one of diol monomers for polymer production, was studied (Scheme 4).

Conclusion

A number of orthodox chemical methods that are applicable to practical retro-polymerization of poly-condensation polymers, e.g., PET, PC, poly(urethane)s and polyamides are known. Most of these recycling reactions and methods seem to be applicable to practical retro-polymerization of post-manufacturer waste plastics, only a few can be applicable to post-consumer waste plastics (i.e., municipal waste plastics). What is demanded now by the sustainable society is the latter-type of methods which are evidently



Scheme 4

more appropriate than the incineration energy recovery (liquefaction) and coke-substitute, because the latter cannot recover the monomer manufacturing energy by any mean. Nevertheless, the government and chemical industry do not change their incineration policy. This is because (1) extremely inexpensive virgin olefinic polymers are now (only for now ?) available; (2) industries and polymer scientists do not invest appropriate efforts to the recycling science and technology probably they rate this type of study low-class; (3) for industrial polymer production, recycled monomers are unwelcome and obstacle.

Of all things, it should be stressed that the recycling can function only in good combination with chemical industries, plastic processing industries, consumers and recovery systems. Too-much diversity and complexity of plastic products would eventually destroy not only the recycling society but also the chemical industry itself.

References

[1] C. J. Campbell and J. H. Laherrere, *Scientific American,* March (1998). [2] O. Kishiro, *Chemistry and Industry* (Chemical Society of Japan), **51**, 1884 (1998). [3] This definition does not include coke-substitute nor liquefaction to fuel oil. [4] A. Oku, L.-C. Hu, E. Yamada, *J. Appl. Polym. Sci.,* **63**, 595 (1997). [5] L.-C. Hu, A. Oku, E. Yamada, *Polymer Journal,* **29**, 708 (1997). [6] L.-C. Hu, A. Oku, E. Yamada, *Polymer,* **39**, 3841 (1998).