西南交通大学学报

第 58 卷 第 3 期
2023 年 6 月

JOURNAL OF SOUTHWEST JIAOTONG UNIVERSITY

Vol. 58 No. 3
June 2023

ISSN: 0258-2724 **DOI：10.35741/issn.0258-2724.58.3.28**

Research article

Chemistry

GLYCOLYSIS OF WASTE PET BOTTLES USING ETHYLENE GLYCOL AS A SOLVENT AND A CALCINED SNAIL SHELL AS A CATALYST

以乙二醇为溶剂、煅烧蜗牛壳为催化剂的废宠物瓶糖酵解

Edith Alagbe*, Ayodeji Ayoola, Adelowo Shokunbi, Oluranti Agboola
Department of Chemical Engineering, Covenant University
Ota, Nigeria, edith.alagbe@covenantuniversity.edu.ng

Received: March 24, 2023 ▪ Reviewed: April 8, 2023
▪ Accepted: May 23, 2023 ▪ Published: June 30, 2023

This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0)

Abstract

With the increasingly widespread use of polyethylene terephthalate (PET) bottles due to their cheap and robust nature, there has been an exponential increase in waste from these bottles in landfills, dumpsites, gutters, and roadsides, which has led to a negative effect on the environment, plants, animals, and human population with land and water pollution. Chemical recycling of the waste PET bottles would reduce the menace and recover the starting monomers for PET production. In this research, waste PET bottles were chemically recycled through glycolysis to produce bis-hydroxyethyl terephthalate (BHET) using ethyl glycol (EG) as a solvent and calcined snail shell as a catalyst within the temperature range of 180-200°C at different EG:PET ratios of 5:1, 6:1, and 6.5:1, while a constant catalyst:PET of 1:100 was used. After reaction and crystallization, a yield of the glycolysis product of 39.72% was obtained. This yield recorded is not as good as using oyster shell (68.6%), sodium acetate (72%), and calcium carbonate (69%) as catalysts. TGA and FTIR indicated that the samples were composed mainly of BHET monomers as functional groups. It is recommended that longer reaction time and varying catalyst:PET ratio be used to determine the optimum temperature and reaction.

Keywords: Glycolysis, Bis-Hydroxyethyl Terephthalate, Chemical Recycling, Polyethylene Terephthalate Depolymerization, Snail Shell

摘要

随着聚对苯二甲酸乙二醇酯(宠物)瓶因其廉价和坚固的特性而越来越广泛地使用，这些瓶子在垃圾填埋场、垃圾场、排水沟和路边产生的废物呈指数级增长，这对环境造成了负面影响环境、植物、动物和人口受到土地和水污染。废宠物瓶的化学回收将减少威胁并回收用于宠物生产的起始单体。在这项研究中，废旧宠物瓶通过糖酵解进行化学回收，以乙二醇(例如)为溶剂，以煅烧蜗牛壳为催化剂，在180-
200摄氏度的不同例如温度范围内生产对苯二甲酸双羟乙酯(BHET)：宠物比率为5:1、6:1和6.5:1，

同时使用恒定催化剂：宠物为1:100。反应结晶后糖酵解产物收率为39.72%。该产率记录不如使用牡蛎壳(68.6%)、乙酸钠(72%)和碳酸钙(69%)作为催化剂。TGA和红外光谱表明样品主要由BHET单体作为官能团组成。建议使用更长的反应时间和不同的催化剂：宠物比率来确定最佳温度和反应.

关键词: 糖酵解，对苯二甲酸双羟乙酯，化学回收，聚对苯二甲酸乙二醇酯解聚，蜗牛壳

I. Introduction

Polyethylene terephthalate (PET) is a tough and rigid artificial fiber and resin that belongs to the polyester family of polymers. Plastic bottles manufactured out of PET have become increasingly popular because of their excellent resistance to rupture, temperature, and gas passage, and even their reduced cost and weight compared with other packing materials like glass and metals. PET is now being used to manufacture well over half of all synthetic fiber and practically all containers of soda and water [1]. Despite the positive attributes of PET bottles, their disposal is a major challenge. Due to significant adverse environmental impact, economic considerations, and human health, the non-degradability of PET is a major hurdle to dumping this trash using traditional methods such as landfilling and incineration [2-4]. Considering ecological and economic considerations, recycling is considered as one of the most promising ways of addressing the issue of PET waste accumulation.

Plastic waste management procedures include burning, landfilling, and recycling. This portends major strategies for waste PET bottle recycling management and energy recovery as a fallout of their disposal [5, 6]. Plastic recycling is extremely poor globally, and large amounts of plastic are disposed of in landfills, where they remain for hundreds of years without naturally degrading. One ton of recycled plastics saves 5.74 cubic meters of landfill area and collecting and transportation costs. Mechanical recycling includes crushing and grinding to reduce PET particle size, re-extrusion, and reprocessing to create new PET products [7]. At the same time, depolymerization, purification, and repolymerization are the steps in the chemical recycling process. Incineration is the last resort where other management strategies are unavailable due to the high cost or lack of facilities for recycling. Incineration is quite environmentally unfriendly, with the emission of toxic gases [8].

Chemical recycling strategies include methanolysis – degradation of the waste PET using ethylene glycol at elevated temperatures to form bis (2-hydroxyethyl) terephthalate (BHET) [9], aminolysis – degradation of PET using amines or ammonia to obtain BHET [10]; hydrolysis, which occurs in either an acidic, alkaline, or neutral environment to yield monomers of terephthalate acid (TPA) [11]; and glycolysis, where PET is degraded into oligomers and monomers [12].

II. Methods/Materials

A. Collection and Preparation of the Samples

Waste PET bottles were collected from plastic bins at Covenant University, Ota, Nigeria. The bottle caps, protective rings, and labels were removed from the bottles, then washed and rinsed with water to remove contaminants. Afterwards, the bottles were cut into a small size of 5 mm by 5 mm and air-dried to remove any moisture before being stored in closed containers.

B. Calcination of the Snail Shell

10 g of ground snail shell was heated in a furnace for two hours at 850°C. It was then kept in a desiccator to cool to room temperature, 27^0C, then stored in a closed container.

C. Glycolysis of PET Bottles

At a constant mass of 0.1 g of a snail shell catalyst, with 10 g of waste PET, but at EG:PET ratios of 5:1, 6:1, and 6.5:1 at temperatures of 180^0C, 190^0C, and 200^0C, the waste PET and EG were charged into a three-necked round bottom flask, which was connected to the condenser, with a thermometer placed in one of the necks. This was placed on a hot plate and subjected to the reaction at different temperatures with a magnetic stirrer for adequate mixing at 500 rpm. The reaction time was two hours. After two hours, the reaction mixture was allowed to cool to room temperature to stop the reaction.

100 g of boiled distilled water was added (at room temperature) to remove excess ethyl glycol (EG), and the solution was filtered by gravity filtration. The filtrate was heated on a hot plate until it became clear and allowed to cool to room temperature before being placed in the refrigerator at 10°C for 16 h for the crystallization of BHET.

The crystallized solution was then filtered

under vacuum, and the BHET was obtained as the filtride, weighed, and stored in a small enclosed container in the refrigerator.

The reaction was then repeated at other temperatures and EG:PET ratios (Table 1).

Table 1.
Schedule of the activities

Temp.	EG:PET ratio	EG:PET ratio	EG:PET ratio
180 ^{0}C	5:1	6:1	6.5:1
190 ^{0}C	5:1	6:1	6.5:1
200 ^{0}C	5:1	6:1	6.5:1

Note: The constant catalyst:PET ratio - 1:100.

A schematic representation of the steps involved is presented in Figure 1.

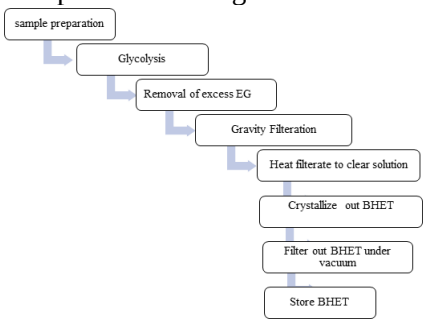

Figure 1. Schematic representation of the glycolysis steps

D. Characterization of BHET

FTIR and thermogravimetric analysis (TGA) were carried out on the reaction product, BHET.

III. Results and Discussion

The mass of BHET and the computed yields are presented in Tables 1 and 2.

Table 2.
Mass of BHET recovered in grams (g) using the calcined snail shell as a catalyst

	EG:PET ratio		
Temp. (°C)	05:01	06:01	06.5:01
180	1.6785	2.4113	3.022
190	1.6789	2.570	3.728
200	3.182	3.422	3.972

The results of TGA and FTIR are presented in Figures 2-13.

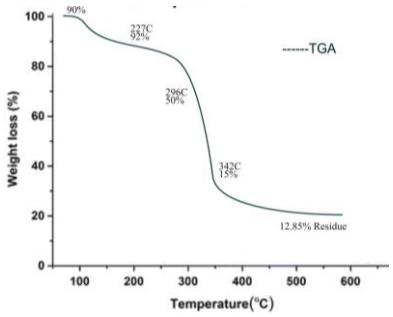

Figure 2. TGA at 5:1 (EG:PET ratio) at 190°C using a calcined snail shell as a catalyst

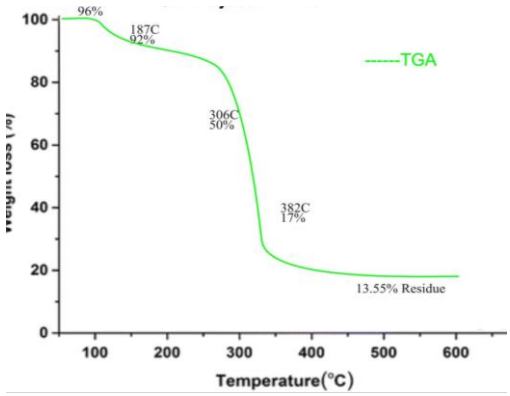

Figure 3. TGA at 6.5:1 (EG:PET ratio) at 180°C using a calcined snail shell as a catalyst

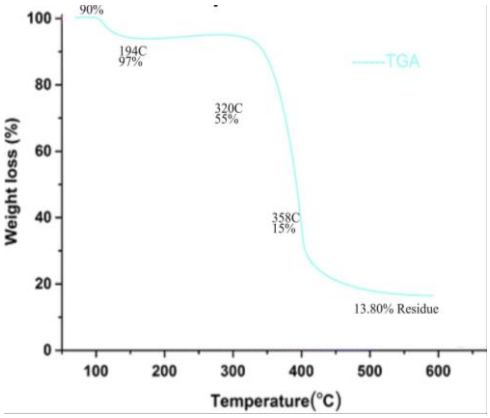

Figure 4. TGA at 6.5:1 (EG:PET ratio) at 190°C using a calcined snail shell as a catalyst

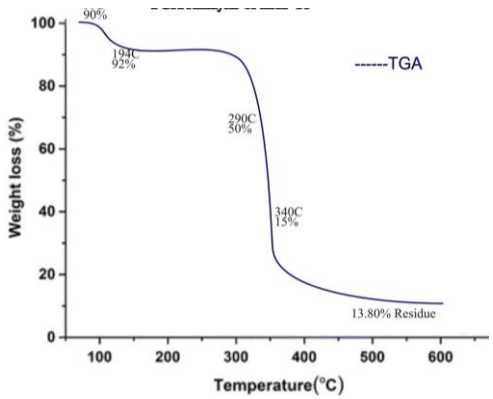

Figure 5. TGA at 5:1 (EG:PET ratio) at 190°C using a calcined snail shell as a catalyst

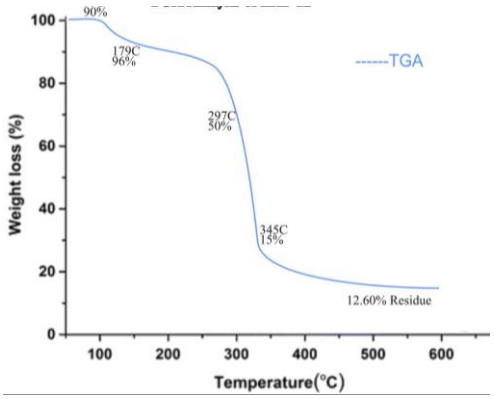

Figure 6. TGA at 6:1 (EG:PET ratio) at 190°C using a calcined snail shell as a catalyst

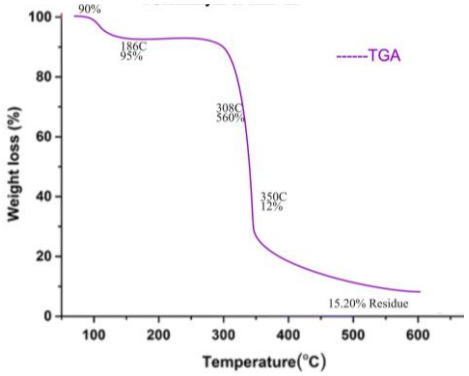

Figure 7. TGA at 6.5:1 (EG:PET ratio) at 200°C using a calcined snail shell as a catalyst

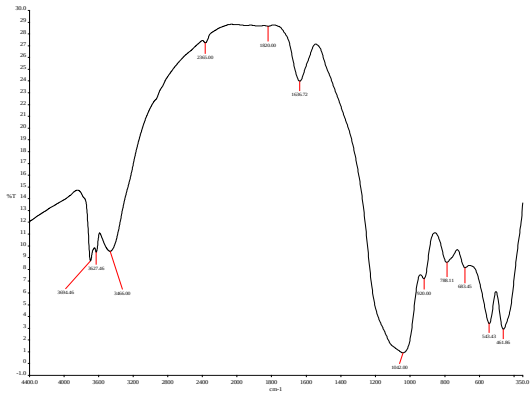

Figure 8. FTIR at 6:1 (EG:PET ratio) at 190°C using a calcined snail shell as a catalyst

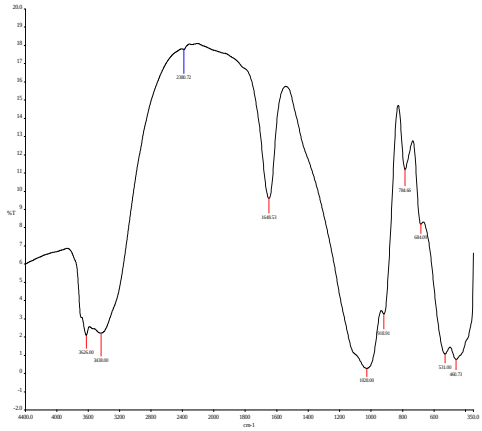

Figure 9. FTIR at 6.5:1 (EG:PET ratio) at 200°C using a calcined snail shell as a catalyst

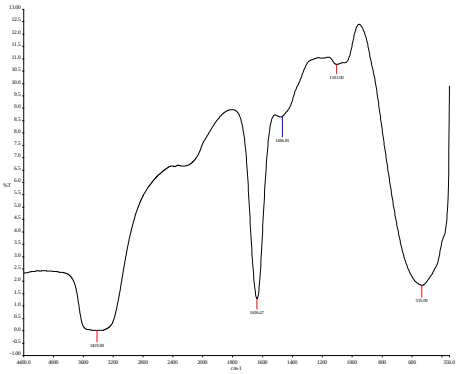

Figure 10. FTIR at 6.5:1 (EG:PET ratio) at 190°C using a calcined snail shell as a catalyst

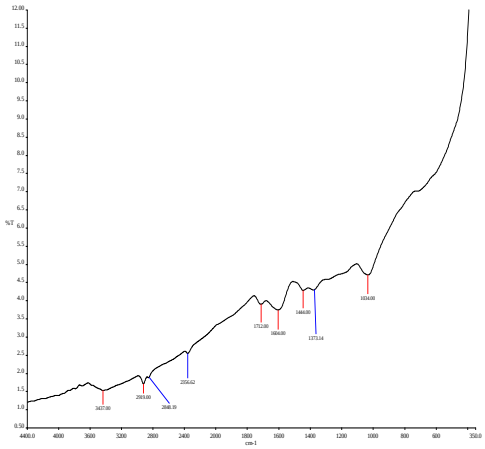

Figure 11. FTIR at 6.5:1 (EG:PET ratio) at 180°C using a calcined snail shell as a catalyst

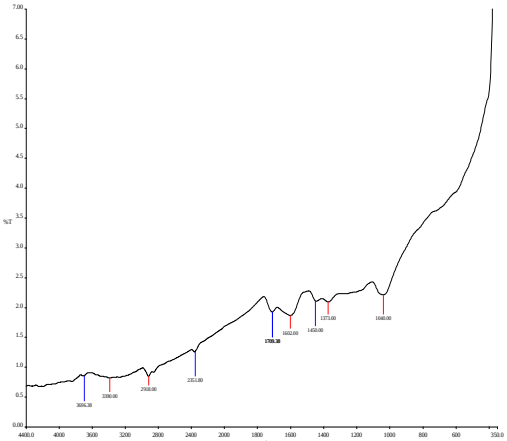

Figure 12. FTIR at 5:1 (EG:PET ratio) at 190°C using a calcined snail shell as a catalyst

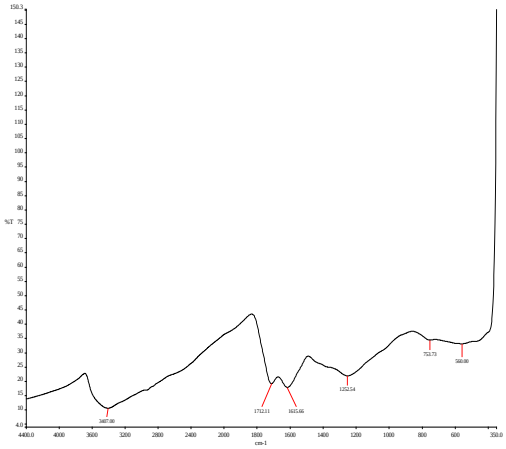

Figure 13. FTIR at 5:1 (EG:PET ratio) at 180°C using a calcined snail shell as a catalyst

A. Effect of Temperature

It was observed from Tables 2 and 3 that the increase in temperature at constant mass of PET bottles and catalyst increased the BHET yield when using a calcined snail shell as a catalyst. Compared to the results by Lopez-Fonseca et al. [13], it is similarly observed that an increase in the reaction temperature will increase the efficiency of the reaction.

Table 3.
BHET yield in percentage (%) using the calcined snail shell as a catalyst

	EG:PET ratio		
Temp. (°C)	**05:01**	**06:01**	**06.5:01**
180	16.785	24.113	30.220
190	16.789	25.700	37.280
200	31.820	34.220	39.720

Also, trends by Yunita et al. [14] show that as the temperature increased above 180°C, the yield increased sharply. Furthermore, the investigation states that the thermal effect on the reaction efficiency is stronger compared with the catalytic effect concentration [15].

The calcined snail shell used as a catalyst for PET glycolysis depolymerization has shown a performance that is less superior to the oyster shell-derived catalyst [16], which attained 68.6% conversion at 195°C. Also, Kumawat et al. [17], using sodium acetate and calcium carbonate as catalysts, recorded yields of 72% and 69%, respectively, at 190^0C.

B. Effect of the Solvent:PET Ratio

The amount of solvent used was observed to significantly impact the final yield. Other glycols, such as ethylene glycol (EG), neopentyl glycol (NPG), propyl diethylene(PG), and diethylene glycol (DEG), can be used in glycolysis reactions. However, EG is more suitable and gives remarkable results in PET depolymerization [18].

The results in Table 2 indicate that higher amount of solvent with the same mass of PET recorded a much higher yield of BHET. It was observed that the most significant factor affecting the reaction is the EG/PET ratio. From the increasing ratio, the decomposition rate is increased, producing lower-weight oligomers. However, this solvent/PET ratio reaches a peak value, the balance between EG, oligomers, and BHET is established, and the degradation rate reaches a constant value [14].

Comparing the trend in Table 2 with previous works from Yunita [14] and Chandel [19], a similarity is observed as the increase in the solvent:PET ratio results in an increased final product.

C. Thermal Analysis

TGA curves of the glycolysis product are shown in Figures 2-8. The first decomposition occurs averagely in the temperature range of 110-140°C, and the second occurs between 300°C and 320°C. The samples were thermally stable up to 110°C before beginning to break down at 120°C. The rapid mass loss occurred during the initial stage of decomposition in the temperature range of 120-140°C, with 19% of the component decomposing. The second mass loss happened between 300°C and 320°C, and a higher percentage of components, 56%, disintegrated.

The first mass loss occurred during the thermogravimetric analysis due to the temperature degradation of the BHET monomer. In contrast, the second mass loss is a result of the temperature degradation of the high chain oligomers or PET, which are created by the thermal polymerization of the BHET monomer. The result agrees with previous research by Wang et al. [18] in determining the thermal properties of glycolysis products.

D. FTIR (Fourier-Transform Infrared Spectroscopy)

Three FTIR spectra of the glycolysis product are shown, and some samples show similar spectra, which also agrees with the BHET control spectrum in a previous report by Syarriffudeen et al. [20].

When comparing the functional groups in the BHET molecule with the samples, it was observed that the BHET functional groups were present. The spectrum showed differences in the molecules. However, the varying sharpness of the peak can account for the variable sample purity. It is assumed that the highest purity was at 180°C with 1:6.5 (PET:EG ratio) using calcined snail shell as the catalyst because of a more substantial peak in Figures 8-13.

IV. CONCLUSION

This research has shown that snail shells can be effectively used as catalysts in glycolysis of PET in ethylene glycol but with a yield of 39.72%. This yield is less than 68.6 % when oyster shells are used as catalysts. This may be attributed to higher presence of CaO (the active reaction ingredient) in oyster shells than in snail shells. Also, environmentally friendly sodium acetate and calcium carbonate used as catalysts have given 72% and 69% yields, respectively. In previous works, longer reaction times (8 hours) have been observed to provide higher yields with other catalysts. Therefore, longer than 2-hour reaction time and varying catalyst:PET ratio are recommended for further research.

ACKNOWLEDGMENT

The team appreciates the support of the Management of Covenant University in the publication of this research work.

REFERENCES

[1] SPASOJEVIĆ, P., PANIĆ, V., DŽUNUZOVIĆ, J., MARINKOVIĆ, A.D., WOORTMAN, A., LOOS, K., and POPOVIĆ, I.G. (2015) High performance alkyd resins synthesized from postconsumer PET bottles. *RSC Advances*, 5 (76), pp. 62273-62283.

[2] MARK, O., EDE, A., OLOFINNADE, O., BAMIGBOYE, G., OKEKE, C., OYEBISI, S., and ARUM, C. (2019) Influence of Some Selected Supplementary Cementitious Materials on Workability and Compressive Strength of Concrete–A Review. *IOP Conference Series: Materials Science and Engineering*, 640, 012071.

[3] OJEWUMI, M., OBANLA, O., FAGBIELE, O., and KOLAWOLE, O. (2022) Land remediation and reclamation techniques through the biodegradation of waste papers. *Journal of Southwest Jiaotong University*, 57 (4), pp. 28-40.

[4] OKEKE, C.A., UNO, J., ACADEME, S., EMENIKE, P.C., ABAM, T.K., and OMOLE, D.O. (2022) An integrated assessment of land use impact, riparian vegetation and lithologic variation on streambank stability in a peri-urban watershed (Nigeria). *Scientific Reports*, 12 (1), 10989.

[5] BAŁAZIŃSKA, M., KRUCZEK, M., and BONDARUK, J. (2021) The environmental impact of various forms of waste PET bottle management. *International Journal of Sustainable Development & World Ecology*, 28 (5), pp. 473-480.

[6] EFEOVBOKHAN, V.E., AKINNEYE, D., AYENI, A.O., OMOLEYE, J.A., BOLADE, O., and ONI, B.A. (2020) Experimental dataset investigating the effect of temperature in the presence or absence of catalysts on the pyrolysis of plantain and yam peels for bio-oil production. *Data in Brief*, 31, 105804.

[7] SCHYNS, Z.O. and SHAVER, M.P. (2021) Mechanical recycling of packaging plastics: A review. *Macromolecular Rapid Communications*, 42 (3), 2000415.

[8] ZHANG, R., MA, X., SHEN, X., ZHAI, Y., ZHANG, T., JI, C., and HONG, J. (2020) PET bottles recycling in China: An LCA coupled with LCC case study of blanket production made of waste PET bottles. *Journal of Environmental Management*, 260, 110062.

[9] HAN, M. (2019) Depolymerization of PET bottle via methanolysis and hydrolysis. In: THOMAS, S., RANE, A., KANNY, K., ABITHA, V.K., and THOMAS, M.G. (eds.) *Recycling of Polyethylene Terephthalate Bottles: Plastics Design Library*. Elsevier, pp. 85-108.

[10] AL-SABAGH, A., YEHIA, F., ESHAQ, G., RABIE, A., and ELMETWALLY, A. (2016) Greener routes for recycling of polyethylene terephthalate. *Egyptian Journal of Petroleum*, 25 (1), pp. 53-64.

[11] ARIAS, J.J.R. and THIELEMANS, W. (2021) Instantaneous hydrolysis of PET bottles: An efficient pathway for the chemical recycling of condensation polymers. *Green Chemistry*, 23 (24), pp. 9945-9956.

[12] XIN, J., ZHANG, Q., HUANG, J., HUANG, R., JAFFERY, Q.Z., YAN, D., ZHOU, Q., XU, J., and LU, X. (2021) Progress in the catalytic glycolysis of polyethylene terephthalate. *Journal of Environmental Management*, 296, 113267.

[13] LÓPEZ-FONSECA, R., DUQUE-INGUNZA, I., DE RIVAS, B., FLORES-GIRALDO, L., and GUTIÉRREZ-ORTIZ, J.I. (2011) Kinetics of catalytic glycolysis of PET wastes with sodium carbonate. *Chemical Engineering Journal*, 168 (1), pp. 312-320.

[14] YUNITA, I., PUTISOMPON, S., CHUMKAEO, P., POONSAWAT, T., and SOMSOOK, E. (2019) Effective catalysts derived from waste ostrich eggshells for glycolysis of post-consumer PET bottles. *Chemical Papers*, 73, pp. 1547-1560.

[15] EL-TOUFAILI, F.A., FEIX, G., and REICHERT, K.H. (2006) Kinetics and Mechanistic Investigation of Hydrotalcite-Catalyzed Melt Synthesis of Poly(ethylene terephthalate). *Macromolecular Materials and Engineering*, 291 (9), pp. 1144-1154.

[16] KIM, Y., KIM, M., HWANG, J., IM, E., and MOON, G.D. (2022) Optimizing PET glycolysis with an oyster shell-derived catalyst using response surface methodology. *Polymers*, 14 (4), 656.

[17] KUMAWAT, K.L., PATIL, H., and ATHALYE, A. (2022) Glycolysis of waste PET bottles using sodium acetate and calcium carbonate as catalyst. *Asian Dyer*, 19 (3), pp. 52-55.
[18] WANG, T., SHEN, C., YU, G., and CHEN, X. (2021) Metal ions immobilized on polymer ionic liquid as novel efficient and facile recycled catalyst for glycolysis of PET. *Polymer Degradation and Stability*, 194, 109751.
[19] CHANDEL, N.S. (2021) Glycolysis. *Cold Spring Harbor Perspectives in Biology*, 13 (5), a040535.
[20] SYARIFFUDDEEN, A., NORHAFIZAH, A., and SALMIATON, A. (2012) Glycolysis of poly(ethylene terephthalate) (PET) waste under conventional convection-conductive glycolysis. *International Journal of Engineering Research and Technology*, 1 (10), pp. 1-8.

参考文:

[1] SPASOJEVIĆ, P., PANIĆ, V., DŽUNUZOVIĆ, J., MARINKOVIĆ, A.D., WOORTMAN, A., LOOS, K. 和 POPOVIĆ, I.G. (2015)
由消费后宠物瓶合成的高性能醇酸树脂。远程控制中心预付款，5 (76)，第 62273-62283 页。
[2] MARK, O., EDE, A., OLOFINNADE, O., BAMIGBOYE, G., OKEKE, C., OYEBISI, S., 和 ARUM, C. (2019)
一些选定的补充胶凝材料对和易性的影响和混凝土的抗压强度——
综述。眼压会议系列：材料科学与工程，640，012071。
[3] OJEWUMI, M.、OBANLA, O.、FAGBIELE, O. 和 KOLAWOLE, O. (2022)
通过废纸生物降解的土地修复和开垦技术。西南交通大学学报，57（4），第 28-40 页。
[4] OKEKE, C.A.、UNO, J.、ACADEME, S.、EMENIKE, P.C.、ABAM, T.K. 和 OMOLE, D.O. (2022)
城市周边流域（尼日利亚）土地利用影响、河岸植被和岩性变化对河岸稳定性的综合评估。科学报告，12 (1)，10989。
[5] BAŁAZIŃSKA, M.、KRUCZEK, M. 和 BONDARUK, J. (2021)
各种形式的废宠物瓶管理对环境的影响。国际可持续发展与世界生态学杂志，28 (5)，第 473-480 页。
[6] EFEOVBOKHAN, V.E.、AKINNEYE, D.、AYENI, A.O.、OMOLEYE, J.A.、BOLADE, O. 和 ONI, B.A. (2020)
实验数据集调查在存在或不存在催化剂的情况下温度对车前草和山药皮热解生物油生产的影响。数据简述，31，105804。
[7] 希恩斯，Z.O. 和 SHAVER, M.P. (2021)
包装塑料的机械回收：综述。大分子快速通讯, 42 (3), 2000415.
[8] ZHANG, R., MA, X., SHEN, X., ZHAI, Y., ZHANG, T., JI, C., 和 HONG, J. (2020)
中国的宠物瓶回收：生命周期评价耦合以低成本航空公司为例，利用废宠物瓶生产毯子。环境管理杂志, 260, 110062.
[9] HAN, M. (2019)
通过甲醇分解和水解对宠物瓶进行解聚。在：THOMAS, S.、RANE, A.、KANNY, K.、ABITHA, V.K. 和 THOMAS, M.G.（编辑）聚对苯二甲酸乙二醇酯瓶的回收：塑料设计图书馆。爱思唯尔，第 85-108 页。
[10] AL-SABAGH, A.、YEHIA, F.、ESHAQ, G.、RABIE, A. 和 ELMETWALLY,
A.（2016）聚对苯二甲酸乙二醇酯回收的绿色路线。埃及石油杂志，25 (1)，第 53-64 页。
[11] 阿里亚斯，J.J.R. 和 THIELEMANS, W. (2021)
宠物瓶的瞬时水解：缩聚物化学回收的有效途径。绿色化学，23 (24)，第 9945-9956 页。
[12]辛静、张清、黄静、黄润、贾佛里清泽、严东、周清、徐静、陆晓 (2021)
聚对苯二甲酸乙二醇酯催化糖酵解研究进展。环境管理杂志, 296, 113267.
[13] LÓPEZ-FONSECA, R.、DUQUE-INGUNZA, I.、DE RIVAS, B.、FLORES-GIRALDO, L. 和 GUTIÉRREZ-ORTIZ, J.I. (2011)
宠物废物与碳酸钠催化糖酵解的动力学。

化学工程杂志，168 (1)，第 312-320 页。
[14] YUNITA, I., PUTISOMPON, S., CHUMKAEO, P., POONSAWAT, T., 和 SOMSOOK, E. (2019) 废鸵鸟蛋壳对消费后宠物瓶糖酵解的有效催化作用. 化学论文，73，第 1547-1560 页。
[15] EL-TOUFAILI, F.A.、FEIX, G. 和 REICHERT, K.H. (2006) 水滑石催化熔融合成聚对苯二甲酸乙二醇酯的动力学和机理研究。高分子材料与工程，291 (9)，第 1144-1154 页。
[16] KIM, Y., KIM, M., HWANG, J., IM, E., 和 MOON, G.D. (2022) 使用响应曲面法用牡蛎壳衍生催化剂优化宠物糖酵解。聚合物，14 (4), 656。
[17] KUMAWAT, K.L.、PATIL, H. 和 ATHALYE, A. (2022) 使用乙酸钠和碳酸钙作为催化剂对废 PET 瓶进行糖酵解。亚洲染坊，19 (3)，第 52-55 页。
[18] WANG, T., SHEN, C., YU, G., 和 CHEN, X. (2021) 固定在聚合物离子液体上的金属离子作为宠物糖酵解的新型高效简便回收催化剂。聚合物降解和稳定性，194，109751。
[19] 钱德尔，N.S. (2021) 糖酵解。冷泉港生物学观点，13 (5), a040535。
[20] SYARIFFUDDEEN, A.、NORHAFIZAH, A. 和 SALMIATON, A. (2012) 传统对流传导糖酵解下聚对苯二甲酸乙二醇酯(宠物)废物的糖酵解。国际工程研究与技术杂志，1 (10)，第 1-8 页。