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Recycle Ability of Post-Consumer Recycled Plastic (PCR) from the Chlorine Tank

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Abstract

Plastic waste that used in our daily life is a major problem of environmental contaminate because it produces microplastics after degradation resulting in the harmful of living organisms, including humans. Therefore, this research has an idea to solve this problem by recycling the plastic waste. High density polyethylene (HDPE) plastic waste from the chlorine tank in fishing industry is considered. This work was designed to blend it with virgin HDPE plastic pellets. The ratio of blended plastics between virgin HDPE pellets and HDPE plastic waste from the chlorine tank which was defined as post-consumer recycled plastic (PCR) was 100:0, 50:50, 40:60, 30:70, 20:80 and 0:100 wt%, respectively. The result shows unchanged thermal properties of plastic blends caused by the same type of polymer, thus the PCR without blending with the virgin HDPE plastic is selected for recycle ability studies. The PCR was rerun in the twin screw extruder in the range of 0 - 80 extruded recycle time to observe the thermal, rheological, mechanical, and physical properties. It was found from our result that 20 recycling time of PCR was appropriate for maximum recycling process due to slightly change rheological characteristics, mechanical properties as well as product's color.

Keywords: High density polyethylene, Post-consumer recycled plastic, Thermal properties, Rheological properties, Mechanical properties

Introduction

Microplastics from plastic consumer product in our daily life is the crucial problem all over the world because the accumulation of microplastics in animals and human body might affect our health. The problem of microplastics in the ocean plays a significant role for marine animals and it might be effect on our life if microplastics contaminate from the marine food pass through our digestive system [1-6]. Eriksen *et al.* [1] found that at least 5.25 trillion pieces of plastic waste, totally more than 268,900 tons of plastic waste, flow into the ocean. In addition, in the year of 2017, United Nations Environment Assembly (UNEP) clarified that the plastic waste was released into the ocean around 4.8 - 12.7 million tons [2]. These are the example of evidence reports that if the single use plastic does not limit to use, the seriously problem of microplastics could increase. Rosset *et al*. [3] studied the types of microplastics in the ocean of Europe and the North America, as well as the North Pole, in depths of over 1,000 meters under the water. This result demonstrated that about 73 % of the polyester fiber was found. Interestingly, many researchers [4-6] selected the sample of marine food consumption and freshwater to observe the microplastics and found the amount of microplastics in the marine food samples more than a half of the total sample test. This result clarified that microplastics were closely with us. Thus, the global trend to reduce the accumulation of plastic waste in the environment by recycling it. Although some of plastic wastes from the manufacturing process have already reproduced by some industries, there are other types of plastic waste from consumer product that have not been recycled. In this research, post-consumer recycled plastic (PCR) which is a plastic waste that has been used by the customer, can be identified the source of plastic waste, and washes it until acceptable before recycling is chosen to study. Currently, the PCR of polyethylene terephthalate (PET) plastic has been successfully recycled and developed as a new consumer product by the Unilever Thai Trading Ltd., Thailand. According to the survey of plastic applications in Thailand, plastic used in an aquaculture and fishing industries which are a large-scale economic activity in the Southeast Asia and Thailand is interesting. The high amount of plastic waste from this industry after survey was polyethylene that used as a chemicals storage tank or aquatic animals' storage tank obtained by fisheries. Fishermen disposed it as a garbage for further disposal after use.

In this work, the high-density polyethylene (HDPE) from the chlorine tank was selected. Firstly, it was blended with a virgin HDPE pellet at different ratio to study the thermal property of plastic blends. Then, the PCR was recycled at 0 - 80 extruded recycle time. The total of recycling time should not be more than 80 extruded recycle time according to the previous reports [7-9] whose found the thermal stability of HDPE that recycled more than 80 cycle time did not change. In addition, the rheological, mechanical and physical properties were explored for further processing production.

Materials and methods

Materials

There are 2 types of plastic used; virgin high-density polyethylene (blow molding grade) and post-consumer recycled plastic (PCR) from the chlorine tank which were supported by Top Trend Manufacturing Co., Ltd., Thailand and Premier Plastech Co., Ltd., Thailand, respectively.

Blending and recycling process

The virgin high density polyethylene (HDPE) and post-consumer recycled plastic (PCR) from the chlorine tank were blended with different ratio at 100:0, 50:50, 40:60, 30:70, 20:80 and 0:100 %wt, respectively processed by twin screw extruder (Lab Tech, LTE20-40, Thailand). The ratio between virgin HDPE and PCR was done with carefully consideration for cover all the possible condition that should be effected on the properties' change after blending these plastics together. The processing temperature was various between 185 - 195 °C and 56 revolutions per minutes (RPM) of screw speed was fixed. The sample that was appropriate for recycling process was rerun by the twin screw extruder with the same condition and sampled it every 5, 10, 20, 50 and 80 extruded recycle time for testing.

Compression molding process

There were 2 types of sample specimen that should be molded which were the sample specimen for rheological properties and mechanical properties. The post-consumer recycled plastic (PCR) from the chlorine tank was compressed in the mold by compression molding machine (Shell Tellus, Shell Tellus 68, Thailand). The sample for rheological measurement was compressed at 190 °C for 20 min using a cylindrical mold with 25 mm of diameter and 2 mm of thickness. Another specimen for mechanical measurement was compressed at the same condition with a square plate of $160\times160\times4$ mm^3 of dimension and cut as a dumbbell shape followed ASTM D638 type II by die cut with hydraulic press.

Characterization

Thermal properties of virgin high density polyethylene (HDPE) and post-consumer recycled plastic (PCR) from the chlorine tank at different ratio were measured by differential scanning calorimetry (NETZSCH, NETZSCH DSC 204 F1 Phoenix, Germany) at temperature ranging between 90 - 400 °C with 10 °C/min of heating rate under the nitrogen gas (N_2). Additionally, the PCR plastic pellet after recycling process was measured the thermal stability by simultaneous thermal analyzer (NETZSCH, NETZSCH STA 449 F3 Jupiter, Germany) at temperature ranging between 27 - 700 °C with 5 °C/min of heating rate under N_2 atmosphere. After that, the gas was switched from N_2 to air during heating at 700 - 1,000 °C with 5 °C/min of heating rate. Moreover, the melt flow index (MFI) of the PCR plastic from the chlorine tank at different extruded recycle time was measured at 230 °C with 3 kg of the pendulum weighs and it was preheated around 6 min before testing every 10 min by melt flow index tester (AMETEX, 5A(T), USA). Then, the rheological property was measured with continuous ramp shear rate and stain sweep at 190 °C to obtain the viscous flow and viscoelastic characteristics of the PCR plastic by rheometer (TA Instruments, Ares-G2 Rheometer, USA). In addition, the PCR plastic from the chlorine tank that compressing and cutting as a dumbbell shape followed ASTM D638 type II was measured mechanical properties using universal testing machine (Narin Instrument CO., LTD, NRI-TS500-50B, Thailand) at 50 mm/min of cross head speed with 40 kN of loading.

Results and discussion

Thermal properties of virgin HDPE blended with post-consumer recycled plastic (PCR)

Thermal properties of the virgin HDPE and PCR blended with various different ratio were determined to clarify their compatibility because the PCR plastic might be mixed with other polymers and chemical ingredients such as pigment and photo protection chemicals during fabricating as the chlorine tanks that might affected thermal properties of PCR product. The results in **Figure 1** shows that the melting temperature (T_m) of their blends at different ratios does not change after various the blend ratio of virgin HDPE and PCR at 100:0, 50:50, 40:60, 30:70, 20:80 and 0:100 %wt, respectively. This might be concluded that PCR plastic from the chlorine tank and the virgin HDPE are compatible because if they are not compatible, the T_m of these 2 types of plastic should be different. This results refers to the same polymer materials without any other polymer blends and it does not consist of other plastic additives that changes thermal properties compared to the virgin HDPE [10,11]. From this results, the pure PCR plastic from the chlorine tank was selected to determine the recycle ability due to the same thermal properties of PCR and virgin HDPE.

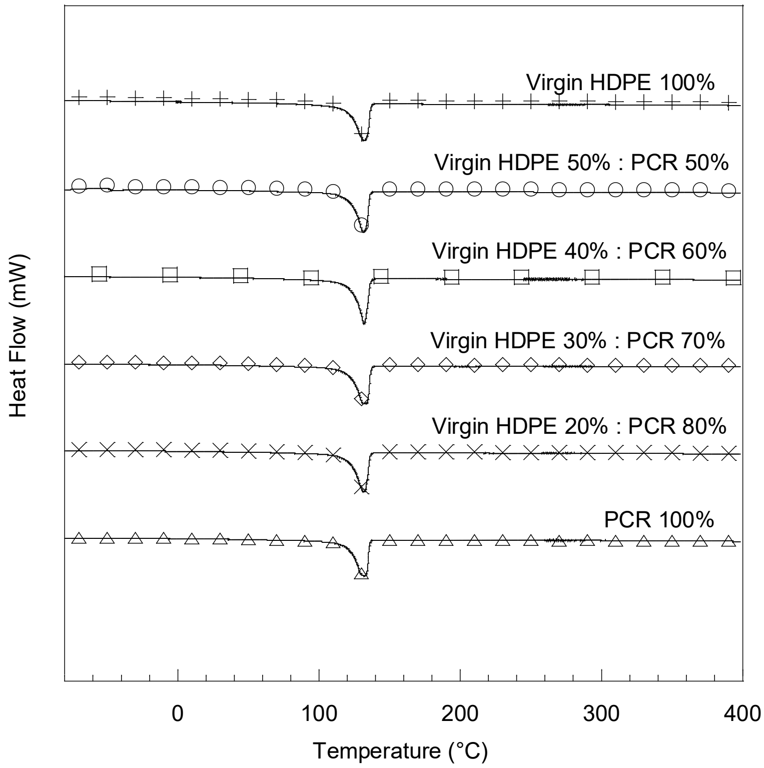

Figure 1 DSC Thermogram of plastic blends between the virgin HDPE and post-consumer recycled plastic (PCR) at different weight ratio.

After performing the differential scanning calorimetry (DSC), the 100 %wt of PCR plastic from the chlorine tank was selected for recycling at 0, 5, 10, 20 and 80 extruded recycle time to study the thermal stability. Thermal degradation of PCR was measured by simultaneous thermal analyzer (STA). The result in **Figure 2** shows the complete percentage of weight loss of our PCR plastic around 300 - 450 °C under N_2 atmosphere referring to the degradation temperature of polyethylene. This might be supported that our PCR plastic does have neither reinforcing filler nor non-combustible additive. In addition, the percentage of weight loss exhibits slightly change after recycling at least 5 extruded recycle time during 300 - 450 °C as shown in **Figure 2b** and it does not change after that until 80 extruded recycle time. Although the thermal degradation of PCR plastic slightly changes after recycling, the flow ability and viscoelastic properties of it might not be the same. Thus, it is necessary to determine the flow behavior and viscoelastic properties of our PCR plastic which would be beneficial for the recycling process in the future.

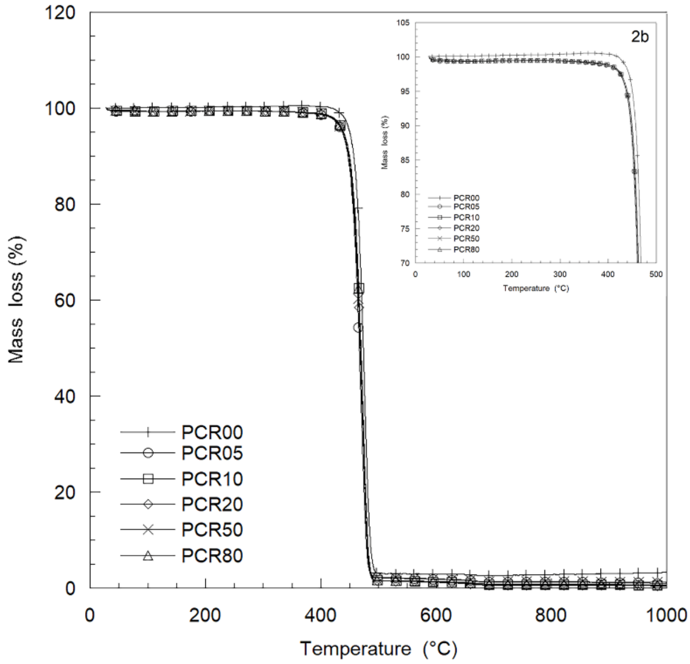

Figure 2 Thermal degradation of post-consumer recycled plastic (PCR) @ 0 (PCR00), 5 (PCR05), 10 (PCR10), 20 (PCR20), 50 (PCR50) and 80 (PCR80) extruded recycle time.

Rheological properties of post-consumer recycled plastic (PCR)

The flow behavior of PCR plastic from the chlorine tank was performed by the melt flow index tester in accordance with ASTM D1238 standard. In **Figure 3**, the melt flow index (MFI) shows the higher value with increasing recycling process around 0 - 10 extruded recycle time. The increase of MFI value caused by the low viscosity of polymer resulting in the high flow ability after measurement. This might be because of the polymer chains scission from the thermal effect. Interestingly, when it was recycled more than 10 extruded recycle time, the MFI value significantly reduced referring to the increase of the polymer viscosity. This could be explained by two reasons. The first reason is when polymer molecules receive enough the shear force with high temperature, the polymer chain would degrade and become as a free radical molecule. The free radical molecule easily reacts with other polymer chain resulting in the longer chain of polymer after recycling. Another reason is the deterioration of polymer molecules to carbon particles, causing the flow behavior of polymers change as the characteristics of polymer suspended with particle [8,12-14]. This thermal decomposition of polymer's molecule into carbon particle as a polymer composites resulted in the increase of the viscosity of PCR plastic after recycling process [10,13].

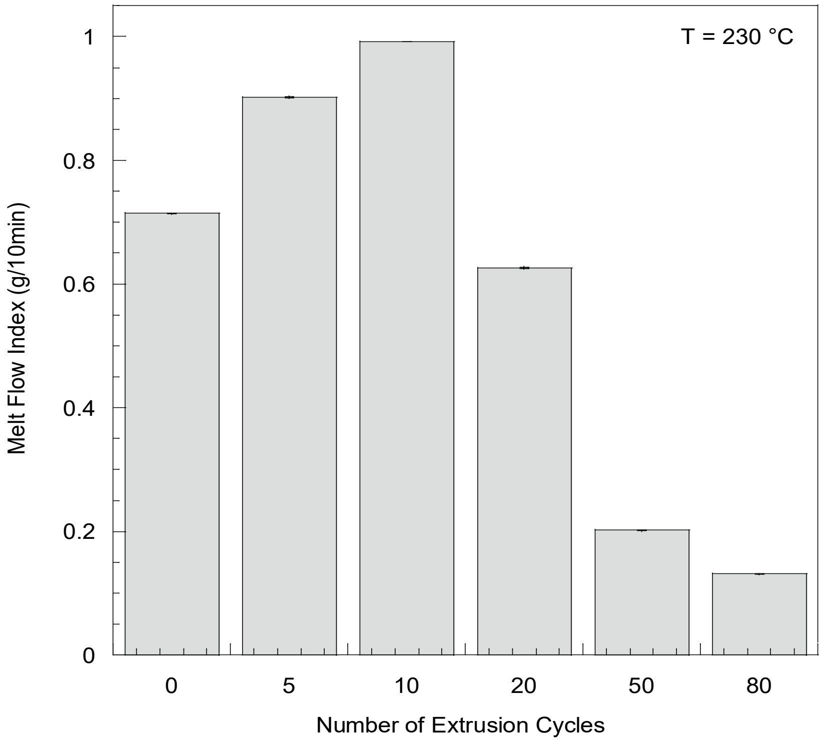

Figure 3 Melt flow index of post-consumer recycled plastic (PCR) @ 0 (PCR00), 5 (PCR05), 10 (PCR10), 20 (PCR20), 50 (PCR50) and 80 (PCR80) extruded recycle time.

In addition, rheological properties should be performed to support the concept of MFI value and considered the flow characteristics of the PCR plastic during shearing force by the twin screw extruder. The PCR plastic from the chlorine tank was measured by parallel plate rheometer with continuous ramp shear rate between 0 - 10 s^{-1}. The condition for testing of rheological properties depended on melt temperature (T_m) of polymer and the nature of flow characteristics of molten polymer after testing which should not be speeded out of the gap between parallel plate during measurement. The viscosity in **Figure 4** increases significantly at low shear rate as shear thinning behavior caused by the connecting of polymer chains by free radical mechanism or the thermal degradation of polymer molecules that produced carbon particle as a reinforcing filler in the polymer matrix as discussed earlier. To clarify which such behaviors occurred, the stain sweep measurement was obtained to observe the linear viscoelastic regime of PCR plastic after recycling process. Storage modulus (G') in **Figure 5**, which represents the elastic solid character of the polymer after recycling process, significantly increases and the linear viscoelastic regime (constant storage modulus region) reduces from 0 - 40 % stain to 0 - 10 % stain after 80 extruded recycle time. This might be concluded that the change of the flow behavior of PCR plastic from the chlorine thank after recycling process is caused by the thermal degradation of polymer molecules as a carbon particle and it acts as a reinforcing filler in polymer matrix. This mechanism results in high shear thinning behavior, high elastic solid characteristics and short linear viscoelastic regime during stain sweep measurement [15]. After rheological properties were obtained, the mechanical and physical properties of the PCR plastic were determined to ensure that our PCR plastic exhibited good quality enough for using as a consumer product after recycling process.

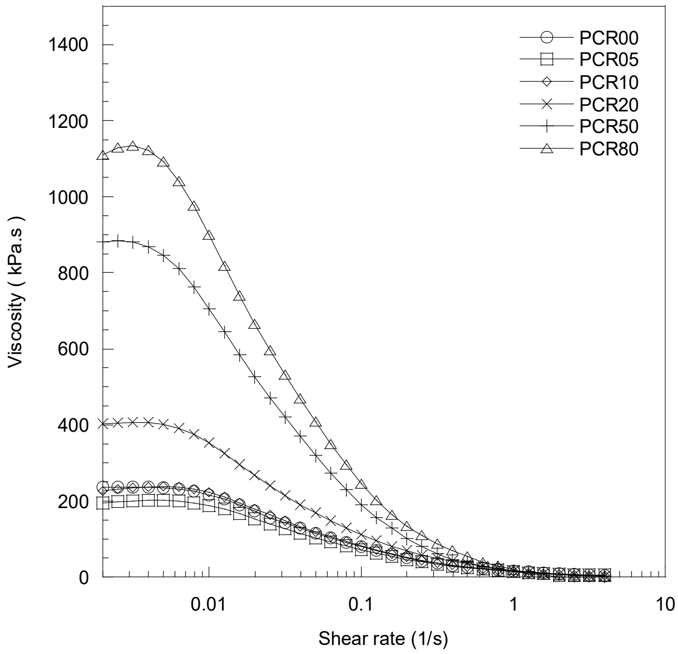

Figure 4 Viscosity of post-consumer recycled plastic (PCR) @ 0 (PCR00), 5 (PCR05), 10 (PCR10), 20 (PCR20), 50 (PCR50), and 80 (PCR80) extruded recycle time.

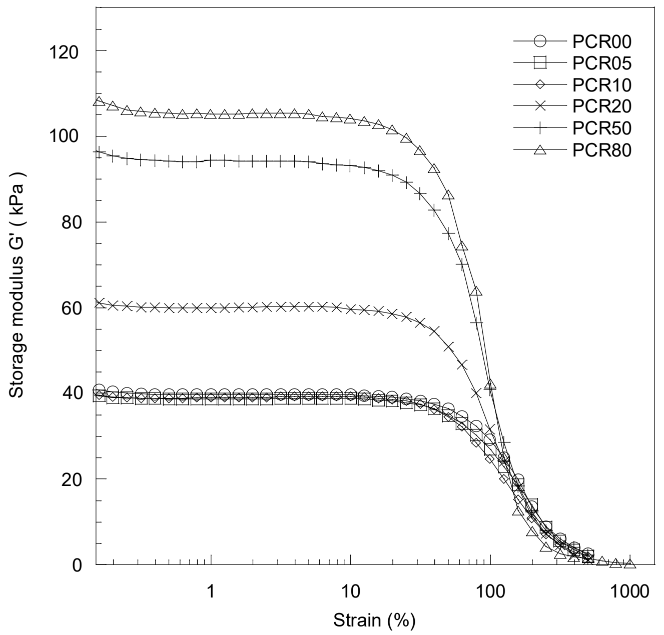

Figure 5 Strain Sweep of post-consumer recycled plastic (PCR) @ 0 (PCR00), 5 (PCR05), 10 (PCR10), 20 (PCR20), 50 (PCR50) and 80 (PCR80) extruded recycle time.

Mechanical and physical properties of post-consumer recycled plastic (PCR)

Mechanical properties of dumbbell shape sample specimen followed ASTM D638 type II are shown in **Table 1**. The yields stress, elongation at break and stress at break of PCR plastic after recycling from 0 - 50 extruded recycle time are similar while mechanical properties slightly reduce after recycling more than 50 extruded recycle time. This can be supported by many researchers [16-18] that the thermal degradation and the shear force after reprocess could reduce the mechanical properties due to the chain scission and the thermal degradation of polymer molecules after recycling as mentioned earlier in rheological properties. However, the physical property in term of plastic product's color was observed as seen in **Figure 6** to ensure that the color of PCR plastic could be acceptable to use as a consumer product. This property is the significant factor for recycle plastic of consumer product when it would be reprocessed because it should be considered for accepting by the customer. The result shows that the color of the product significantly changes after 20 extruded recycle time (PCR20) compared with PCR plastic without recycling process (PCR00). It can be concluded from mechanical properties and the physical property in term of product's color that this type of PCR plastic can be maximum re-formed around 20 - 50 extruded recycle time for acceptable to use as a consumer container product.

Table 1 Mechanical properties of post-consumer recycled plastic (PCR) @ 0 (PCR00), 5 (PCR05), 10 (PCR10), 20 (PCR20), 50 (PCR50) and 80 (PCR80) of extruded recycle time.

Name	Yield stress (MPa)	Elongation (%)	Stress at break (MPa)
PCR00	30.73±0.54	89.47±21.13	13.54±0.90
PCR05	31.48±0.10	81.87±14.08	13.32±1.10
PCR10	31.51±1.35	77.52±12.81	13.18±1.22
PCR20	30.05±0.20	80.28±18.88	13.29±0.74
PCR50	29.57±0.74	78.72±19.94	11.37±1.18
PCR80	27.66±0.14	59.21±10.32	11.58±1.15

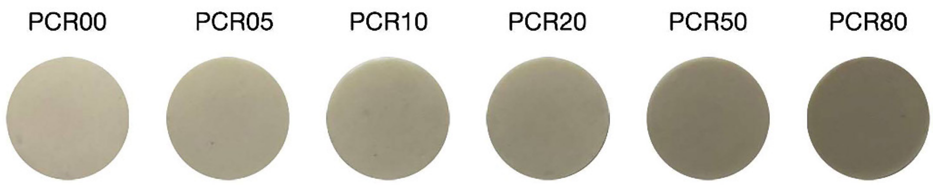

Figure 6 Product's color of post-consumer recycled plastic (PCR) @ 0 (PCR00), 5 (PCR05), 10 (PCR10), 20 (PCR20), 50 (PCR50) and 80 (PCR80) of extruded recycle time.

Conclusions

The post-consumer recycled plastic (PCR) from the chlorine tank blended with the virgin high density polyethylene (HDPE) found the same thermal characteristics at different weight ratio of blending measured by the differential scanning calorimetry (DSC) meaning that the PCR plastic was the same type of the virgin HDPE and did not adulterated with other polymer or chemical additives that affected thermal properties. Thus, the pure PCR plastic was chosen to determine the feasibility of recycling time by the twin screw extruder. The pure PCR from the chlorine tank was recycled from 0 to 80 time of recycles. The results showed that thermal properties of PCR plastic did not change significantly after recycling process. However, the melt flow index (MFI) gradually increased at the beginning of recycling process and decreased after 10 extruded recycle time, respectively. The increase of MFI value at the beginning caused by the chains scission of polymer molecules from thermal and shear force effect while the reduction of MFI value after 10 extruded recycle time would be the thermal degradation of polymer molecules as a carbon particle resulting in shear thinning flow character with high storage modulus **(G')** and low linear viscoelastic regime. Moreover, the mechanical properties of our PCR plastic slightly reduced, and the color of PCR product significantly changed after 20 extruded recycle time compared with PCR plastic without recycling process. These could be concluded that the PCR plastic from the chorine tank should not be recycled more than 20 extruded recycle time by the twin screw extruder.

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