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Resource utilization of medical waste under COVID-19: Waste mask used as crude oil fluidity improver

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ABSTRACT

The disposal of medical waste has become an increasing environmental issue since the COVID-19 epidemic outbreaks. Conventional disposal methods have produced waste of fossil resources and environmental problems. In this study, the waste medical mask-derived materials were tested as viscosity reducer and pour point depressant to evaluate the possibility of being used as crude oil fluidity improver. The results show that the materials derived from the three parts of the waste medical mask can reduce the viscosity and pour point of each crude oil samples from different oilfields in China. The middle layer of the medical mask (PP-2) displays the highest efficiency, and the viscosity reduction rate and maximum pour point reduction reaches 81% and 8.3 °C at 500 ppm, respectively. A probable mechanism of improving rheological properties of the crude oil samples by the medical mask-derived materials was further proposed after the differential scanning calorimetry (DSC) analysis and the wax crystal morphology analysis. We hope this work could provide a way to solve the current environmental issues under COVID-19.

1. Introduction

Medical masks and other medical supplies are playing an irreplaceable role in prevention and control of COVID-19 epidemic. However, these waste medical supplies have caused waste of resources and produced environmental issues as present in Fig. 1. Traditionally, the waste masks were incinerated, landfilled, and even dumped at will. On one hand, improper disposal of the waste masks leads to the pollution of environment and human health risks (Sharma et al., 2020; Silva et al., 2021; Nowakowski et al., 2020). On the other hand, as the huge amount of resources are wasted, the consumption of fossil fuels and carbon emissions are increased (Klemeš et al., 2020; Abdel-Shafy and Mansour, 2018; Sharma Sudhakara et al., 2021). The resource re-utilization of polymer waste (e.g., masks, etc.) is an essential way to controlling environmental pollution, reducing the carbon emissions and saving investment needs (Kimm et al., 2020; Zhang et al., 2020; Naqvi et al., 2018).

At present, physical recycling and chemical recycling are mainly used to improve the collection and utilization of the waste. Physical recycling, which means that waste is sorted according to materials, broken into plastic particles, and then added to the raw materials in a certain proportion for recycling products (Xu et al., 2021; Sadat-Shojai and Bakhshandeh, 2011; Froelich and Maris, 2020). Chemical recycling refers to the converting the waste into petroleum, natural gas, chemicals and monomers through the processes of hydrocracking, oilification, vaporization, pyrolysis and polycondensation (Dogu et al., 2021; Davidson et al., 2021; Dharmaraj et al., 2021). Dharmaraj et al. summarized the pyrolysis technology of medical waste, which was converted into valuable energy products such as oil, natural gas and coke through the pyrolysis process (Dharmaraj et al., 2021). Polymer waste can also be recycled to produce composites. Deka and Maji prepared wood plastic composite by blending of high density polyethylene, polypropylene, polyvinyl chloride, wood flour, modified montmorillonite and glycidyl methacrylate (Deka and Maji, 2011). However, the energy consumption required for the above processes and the requirements for technology and equipment are relatively strict, making it difficult to industrialize.

In reality, the main challenges of recycling are the cost and benefit

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In recent years, polymer solutions have been widely used in many oilfields and achieved remarkable results. The main component of the medical mask is polypropylene (PP), the molecular structure of which is similar to that of the crude oil flow improvers, such as polyethylene (Bucaram, 1967), branched polyethylenes (Robinson et al., 2016), viscosity reducers and pour point depressants (Wei et al., 2014; Chen et al., 2018). In the field of oilfield chemistry, such polymers are often used as oil-displacing agents, polyethylene-vinyl acetate (EVA) (Yang et al., 2019), etc. In practical applications, the flow improver is generally pumped into the oil in the wellbore or pipeline in a certain proportion to achieve its flow improvement.

In recent years, polymer solutions have been widely used in many oilfields and achieved remarkable results. The main component of the medical mask is polypropylene (PP), the molecular structure of which is similar to that of the crude oil flow improvers, such as polyethylene (Bucaram, 1967), branched polyethylenes (Robinson et al., 2016), polyethylene-vinyl acetate (EVA) (Yang et al., 2019), etc. In the field of oilfield chemistry, such polymers are often used as oil-displacing agents, viscosity reducers and pour point depressants (Wei et al., 2014; Chen et al., 2011; Deka et al., 2020). Our research group has put forward the idea of possible resource utilization of medical waste based on PP as present in this research. In this study, the waste medical mask was modified as a viscosity reducer and a pour point depressant to study its performance in enhancing the flow ability of the crude oil samples. Furthermore, a proposed mechanism of the prepared flow improver was provided based on the differential scanning calorimetry (DSC) analysis and wax crystal morphology analysis.

2. Experimental

2.1. Materials

Acetone, toluene, octanol and chloroform all with analytically pure were supplied from Xi’an Chemical Agent Co., Ltd. Waste mask materials were collected at recycling points in Xi’an Shiyou University. The crude oil samples were obtained from Henan Oilfield and Yanchang Oilfield. The names of crude oil sample were abbreviations of different oil fields or its block. The physical parameters of the four samples were summarized in Table 1. The viscosity and pour point of each crude oil sample were measured according to the standards of SY/T 0520–2008 and SY/T 0541–2009 respectively (SY/T0520-2008, 2008; SY/T0541-2009, 2009). The distribution of SARA (saturates, aromatics, asphaltenes, resins) fractions of each oil sample was measured according to the standard of SY/T 5119-2008 (SY/T 5119-2008, 2008). These fractions were isolated with the silica gel column chromatography method, the asphaltenes content of each sample was determined with the n-heptane method.

2.2. Solubility test

The waste masks used in the experiment were disinfected by alcohol after collected. The three layers of the mask were separated and categorized as shown in Fig. 2, then cut into pieces with 5–6 mm on each side and dissolved in a specific solvent. In order to select a suitable solvent, four commonly used solvents (acetone, toluene, octanol and chloroform) were selected for solubility test. The solubility test was carried out at a polymer concentration of 0.125 g mL⁻¹, the amount of treated mask pieces was 6.25 g per 50 mL solvent. After dissolved in a suitable solvent, the solution containing the inner, middle and outer layers of the mask were named as PP-1, PP-2 and PP-3, respectively, and the solution containing all three layers was named as PP-N. Moreover, PP-1, PP-2, PP-3 and PP-N were collectively named as PPs.

2.3. Performance evaluation

The viscosity of the treated oil samples was tested with the NDJ-8S viscometer at different temperatures according to the standard of SY/T 0520–2008. The rate of viscosity reduction Δη (%) was calculated as follows: \[ \Delta \eta = (\eta_0 - \eta) / \eta_0 \times 100\% \], where \( \Delta \eta \) (%) is the rate of viscosity reduction, \( \eta_0 \) (mPa·s) is the viscosity of the oil before the introduction of flow improver, and \( \eta \) (mPa·s) is the viscosity of the oil after the introduction of flow improver. Before each test, 25 g crude oil was maintained at 50°C for 10 min. Then 100–500 ppm (refer to polymer concentration in the crude oil) PPs solution were added into the oil sample, stirred uniformly and put the measuring cylinder in the constant temperature water bath for 2.5 h. In addition, to explore the performance of PP, blank experiments were carried out at the same time. Then the viscosity of each oil sample was measured using the viscometer. The pour point of each oil sample was measured according to the standard of SY/T0541-2009 (SY/T0541-2009, 2009).

Fig. 1. The pollution and impact of waste medical masks and proposed resource utilization scheme.
2.4. DSC analysis

The DSC analysis of crude oil samples in the absence and presence of 500 ppm PP was performed using the Mettler DSC-822e Calorimeter. The temperature procedure consists of two steps: (1) Heating step: each sample was heated from room temperature to 50 °C at 11 °C/min; (2) Cooling step: each sample was cooled down from 50 °C to 5 °C at 8 °C/min.

2.5. Wax crystal morphology analysis

According to the standard of SY/T 5119-2008, the column chromatography method was used to separate crude oil samples to obtain the saturates. The morphologies of wax crystal in saturated hydrocarbons with and without PPs were observed using an OPTPro-3000 polarizing microscope (Chen et al., 2021; Gu et al., 2018).

3. Results and discussion

3.1. Solubility of the solvents

The middle layer (6.25 g) of a waste mask was dissolved in 50 mL solvents at room temperature as present in Fig. 3a. In acetone, octanol and chloroform, some residuals can be observed, indicating that the materials can not be dissolved completely. In toluene, it was almost completely dissolved, the mixed liquid is transparent. The Tyndall phenomenon under the irradiation of light was observed, indicating that a polymer solution was obtained. In addition, it could fully dissolve after being heated at 60 °C for 15 min as shown in Fig. 3b. Therefore, toluene was selected to dissolve the outer, inner and three-layer mixture. In this way, four fluidity improvers were prepared.

3.2. Performance of viscosity reduction

The PPs were evaluated as viscosity reducers with HNG sample from Henan Oilfield. It can be seen from the results shown in Fig. 4 that the viscosity decreased along with increase of temperature, and all the PPs can significantly reduce the viscosity at the relative low temperature. The selected solvent has little effect on viscosity reduction. Compared to PP-1, PP-3 and PP-N, PP-2 showed the best performance as a viscosity reducer, and the viscosity reduction rate was 71% at 30 °C.

In Fig. 5, the PPs were also evaluated with the YL sample from Henan Oilfield., PPs exhibit different ability in viscosity reduction. Similarly,
PP-2 is more efficient in viscosity reduction than the other viscosity reducers. Especially, PP-2 can reduce the viscosity of YL sample from 372000 mPa s to 70200 mPa s at 30°C, yielding a viscosity reduction rate of 81%.

The PPs were also evaluated with the QHB sample from Yanchang Oilfield. In Fig. 6, it can be seen that the viscosity reduction rate can be increased by increasing the dosage of the PPs. Obviously, PP-N is less effective than the three other viscosity reducers when tested with the QHB sample. The viscosity reduction rate of PP-2 at 500 ppm is 63% at 7.5°C, which indicates that PP-2 is effective in reducing viscosity of crude oil at low temperature conditions.

In addition, the PPs' performance were also evaluated with the HN sample from Henan Oilfield. As shown in Fig. 7, PP-2 have an efficient effect of reducing the viscosity of the oil sample along the whole temperature range, which can reduce viscosity from 341000 mPa s to 91400 mPa s at 30°C, with a viscosity reduction rate of 73%.

3.3. Performance of pour point depression

Using the same crude oil samples, the pour point of each sample was tested. As can be seen from Fig. 8, the pour point of each oil sample can be significantly reduced by the PPs, among which the PP-2 exhibites the best performance of reducing the pour point of the oil samples. For the HNG oil sample, in the presence of 300 ppm PP-2, the HNG oil sample’s pour point is reduced from 12.2°C to 7.4°C. With 300 ppm PP-2, the pour points of YL, QHB and HN samples can be reduced by 8.3°C, 5.7°C and 4.6°C, respectively.

According to relevant literature reports, polymer-based pour point
depressant can inhibit and disturb the crystallization process of paraffin molecules in crude oil to realize the purpose of depressing pour point and viscosity (Zhou et al., 2021; Chen et al., 2018b). The middle layer of the mask is made of melt-blown cloth material, and the inner and outer layers are conventional non-woven fabrics. PP-2 exhibits the highest performance in viscosity reduction and pour point depressing, which may be caused by the difference between the materials of melt blown fabric and non-woven fabric. The non-woven material of the outer and inner layers of the mask was a kind of general polypropylene. The special material for melt blown cloth is polypropylene with high melt index (MI) (Liang and Ness, 1997; Chen et al., 2018c). Polypropylene with higher MI can achieve better filterability of the melt-blown cloth. It was reported that polypropylene with a lower molecular weight would lead to a higher MI (Varshouee et al., 2021). Therefore, polypropylene materials with high MI would have lower molecular weights and better processability. After being heated and dissolved, the melt-blown cloth is more likely to be converted into melt state, which may be contributed by the low molecular weight and short molecular chain of melt-blown polypropylene molecules. Hence, the solubility of the melt-blown polypropylene in the crude oil was found to be higher than that of other PPs, which may facilitate the interactions between melt-blown polypropylene molecules and the paraffin molecules, thereby easily affecting the pour point and viscosity. Therefore, PP-2 has an efficient effect in improving the rheological property of crude oil. The performance of PP-N is relatively lower compared with the other PPs, which may be caused by the weak interaction between the its hydrocarbon chains and the paraffin molecules.

Fig. 6. The performance of viscosity reduction of PPs on QHB sample. (a–d: QHB sample added with PP-1, PP-2, PP-3 and PP-N respectively).

Fig. 7. The performance of viscosity reduction of PPs on HN sample. (a–d: HN sample added with PP-1, PP-2, PP-3 and PP-N respectively).
3.4. DSC analysis

In this section, 500 ppm PP-2 was added into the oil samples and homogenized at 50 °C for DSC analysis. As can be seen in Fig. 9, the peak temperature and wax point (onset temperature) of each oil sample can be decreased by PP-2 at different degrees, which indicates that PP-2 can depress the crystallization of wax. Especially for crude oil with high wax content, the peak temperature and onset temperature of QHB sample in the presence of PP-2 are decreased from 22.13 °C to 20.00 °C, and 28.62 °C–27.00 °C respectively. These results confirm that PP-2 can inhibit the crystallization process of crude oils, thereby broaden the temperature range of flow of crude oils.

3.5. Wax crystal morphology analysis

In order to investigate possible mechanism, the morphologies of wax crystal in liquid hydrocarbons with and without PP-2 were observed. As can be seen in Fig. 10a, the wax crystals without the presence of PP-2 exhibits flocculent structure, which could develop into an aggregated network structure and restrain the liquid hydrocarbon molecules, retarding the flow ability of the hydrocarbons (Gu et al., 2019; Chen et al., 2016). As shown in Fig. 10b, the morphology of wax crystal in the presence of PP-2 exhibits needle-like crystals, and the crystal is well dispersed in the liquid hydrocarbons, which confirms that wax crystals are thinner when PP-2 is added in the liquid hydrocarbons. The results in Fig. 10 indicates that PP-2 can be used as a wax modifier to restrict the growth of wax crystals, leading to the formation of smaller and more dispersed crystals.
growth tendency of wax crystals. Therefore, a regular network of wax disturbances the orientation of wax crystals, which further weakens the growth tendency of wax (Gu et al., 2020; Chen et al., 2015). In this study, it was proposed that the PPs’ alkyl chains can hinder the combination of wax crystals by adsorbing on the crystal surface, co-crystallizing with the wax crystals and modify the crystal morphology. The adsorbed and co-crystallized sites on PPs molecules can grab the wax crystals and break up the aggregates of resins and asphaltene. Therefore, a regular network of wax crystals can be prevented, as shown in Fig. 11. Moreover, these chain-typed molecules may also extend into the space between the resin and asphaltene molecules through the van der Waals forces, breaking up the aggregates of resins and asphaltene.

3.6. Proposed mechanism

According to the above results and analysis, a possible mechanism of the flow improver was proposed. There are several mechanisms including nucleation, adsorption and co-crystallization in the crystallization of wax (Gu et al., 2020; Chen et al., 2015). In this study, it was proposed that the PPs’ alkyl chains can hinder the combination of wax crystals by adsorbing on the crystal surface, co-crystallizing with the wax crystals and modify the crystal morphology. The adsorbed and co-crystallized sites on PPs molecules can grab the wax crystals and break up the aggregates of resins and asphaltene. Therefore, a regular network of wax crystals can be prevented, as shown in Fig. 11. Moreover, these chain-typed molecules may also extend into the space between the resin and asphaltene molecules through the van der Waals forces, breaking up the aggregates of resins and asphaltene.

3.7. Feasibility and cost benefit analysis

The medical waste resource re-utilization method in this research will avoid the environmental pollution caused by medical waste. Therefore, when the results of this research are applied on a larger scale, it is recommended to use high-temperature pretreatment to kill the virus, which can avoid the problem of evaporation after alcohol spraying and simplify the treatment procedure. Whether a mask is an infectious waste needs to be considered in light of the specific environment and using background. In the absence of infectious diseases, masks are used as a protective tool and are not infectious. However, when the epidemic spreads in a certain area, discarded masks are infectious waste, which should be disposed in a specail way beyond the scope of this work. And the waste masks when heated to 60°C are infectious waste, which can avoid the problem of evaporation after alcohol spraying and simplify the treatment procedure. Whether a mask is an infectious waste needs to be considered in light of the specific environment and using background. In the absence of infectious diseases, masks are used as a protective tool and are not infectious. However, when the epidemic spreads in a certain area, discarded masks are infectious waste, which should be disposed in a specail way beyond the scope of this work. And the waste masks when heated to 60°C are infectious waste, which can avoid the problem of evaporation after alcohol spraying and simplify the treatment procedure.

\[ C = M_o C_o + M_{pp} C_{pp} = M_o C_o + M_{pp} (C_1 + C_2 + C_3 + C_4) \]  

where \( C \) is the total costs of the PPs-contained flow improver, \( ¥/ton \); \( M_o \) is the proportion of toluene in the PPs-contained flow improver per ton, which is 0.65 ton/ton; \( C_o \) is the cost of toluene per ton, which is 6211 \( ¥/ton \) now; \( M_{pp} \) is the proportion of the PPs in the flow improver per ton, which is 0.35 ton/ton, and \( C_{pp} \) is the total cost of PPs per ton; \( C_2 \) is the cost of transport, which is estimated to be 100 \( ¥/ton \) (based on close range transport, such as city or community); \( C_3 \) is the cost of processing, which is estimated to be 500 \( ¥/ton \); \( C_4 \) is the cost of packaging, which is estimated to be 800 \( ¥/ton \); \( C_1 \) is the cost of material disinfection, which is estimated to be 16.74 \( ¥/ton \), which is obtained by using equations (2) and (3).

\[ C_1 = C_o Q \]  
\[ Q \times \eta = mc\Delta T \]

where \( C_o \) is the price of the industrial electricity in China, 0.725 \( ¥/kWh \); \( Q \) is the electrical energy consumption of polypropylene based waste masks when heated to 60°C, kWh; \( \eta \) refers to the conversion rate when electrical work is converted to heat, %; \( c \) is the specific heat capacity of PP, which is 1.9 \( J/g°C \) (Grebowicz et al., 1984; Wu, 2011); m

Fig. 10. The wax crystal morphology in saturated hydrocarbons without (a) and with (b) PP-2.

Fig. 11. The co-crystallization and dispersion of PPs flow improver on wax crystals.
is the mass of treated waste masks, g; \(4T\) is the change of temperature during the heat treatment, °C. According to the above formula, from room temperature (25 °C) to 60 °C, the heat required for the virus-killing disposal is 66,500 kJ/tон. Assuming a conversion rate of 80%, the electrical power consumption can be calculated as 23.09 kW h/tон, the heating treatment cost is calculated as 16.74 ¥/tон. All the cost calculations related to the similar work or process in Xi’an Changqing Chemical Group Co., Ltd, which is the largest company of oil field chemical production in Xi’an.

This research provides a new resource utilization way based on large amount of waste masks since the COVID-19 epidemic outbreaks. The feasibility was clarified by analyzing and discussing the controllable factors simply, while the specific and detailed implementation requires cooperation with multiple departments related to waste collection, disinfection, transfer, and processing.

4. Conclusions

In this study, polypropylene based waste medical masks were used as crude oil flow improvers, and it was an example to explore the possibility of resource re-utilization. The results show that PPs can reduce the viscosity and depress the pour point of crude oil in a certain temperature range, among which PP-2 is the most potential flow improver. PP-2 at 500 rpm can reduce the viscosity by 81% and depress the pour point by 8.3 °C for VI sample, which indicates that PPs are suitable flow improvers for crude oil with high pour point or heavy oil. The mechanism was investigated by DSC analysis and crystal morphology observation. PPs might inhibit the growth of wax crystalline structure, and loosen the aggregates of resins and asphaltene molecules, rendering crude oil easier to flow. Considering costs of mask collection, energy consumption and other factors, the total cost of the PPs flow improver was ~4533 ¥ (obtained from Equation (1)), which was much lower than the similar polymer viscosity reducers. This work provides a way to solve the current environmental problems under the COVID-19 pandemic.

CRediT authorship contribution statement

Peng Wang: Investigation, Data curation, Writing – original draft.
Xuefan Gu: Data curation, Investigation, Formal analysis.
Ming Xue: Data curation, Investigation.
Yongfei Li: Validation, Conceptualization, Supervision.
Sanbao Dong: Formal analysis, Investigation, Gang Chen: Methodology, Project administration, Funding acquisition.
Jie Zhang: Investigation, Validation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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