Analysis and Simulation of Spiral Waste Plastic Electromagnetic Cracking Reactor

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Abstract. Domestic garbage contains a lot of waste plastic. Due to the stable physical and chemical structure, it may not be decomposed in the natural environment for tens to hundreds of years, so the waste plastics cause serious pollution and harm to the environment. Using electromagnetic heating technology and double-helical propulsion structure, Continuous and efficient cracking of waste plastics reactor can produce useful oil, cracking gas and carbon black to achieve the purpose of high value recycling of waste plastics.

1. Introduction
The traditional treatment methods of domestic garbage containing a large amount of waste plastic are mainly incineration and landfill, but the incineration of waste plastic will produce a variety of toxic gases and pollute the environment. Landfilling of waste plastic will also pollute land and water resources [1]. Although these two traditional treatment methods can solve the problem of accumulation and storage of domestic garbage, they will cause considerable damage to the environment. Electromagnetic cracking is an efficient and environmentally friendly cracking method. A spiral waste plastic electromagnetic cracking reactor is used to crack the waste plastic obtained through the sorting treatment of domestic waste, which can realize continuous processing of waste plastic. Moreover, the cracked oil and cracked gas generated after the waste plastic cracking treatment can be used as renewable energy, and the carbon black produced can be reused [2].

2. Electromagnetic cracking process
Electromagnetic induction heating [3] is to use high-frequency current to generate an alternating magnetic field through the coil. When the magnetic field lines of the alternating magnetic field pass through the metal, eddy currents will be generated inside the metal, which will generate a lot of Joule heat. The application to electromagnetic cracking is to coil an electromagnetic coil around a spiral tube. After the coil passes high-frequency current, an alternating magnetic field is generated, which causes the metal to generate heat. The heat is transferred to the internal heating material through heat transfer. Figure 1 shows the electromagnetic cracking process of waste plastics.
3. Structural analysis of the reactor

3.1. Reactor structure

According to the characteristics of the plastic and the working characteristics of the electromagnetic heating device [4], the spiral reactor was selected. It has the advantages of simple structure, suitable for a variety of mixed plastics, convenient temperature measurement and control, and uniform stress distribution. In addition, the spiral reactor is more suitable for continuous production. With the special internal structure of the conveying screw, the waste plastic can be uniformly heated, avoid coking, and quickly crack. Figure 2 shows the reactor cavity structure.

In the figure, NO.1 is the inlet; NO.2 is the thermocouple interface; NO.3 is the air outlet; NO.4 is the pressure gauge interface; NO.5 is the outlet; NO.6 is the thermocouple interface; NO.7 is the cracking cavity; NO.8 is the support.

The waste plastic enters the reactor cavity from the feeding port. With the spiral rotation, the waste plastic gradually moves toward the discharging port, and the temperature gradually increases, thereby achieving continuous feeding, continuous cracking, and continuous discharging. Taking into account various factors such as the flow state of waste plastic at high temperature, the winding mode of the electromagnetic coil, the internal double spiral structure, and efficient heat utilization, the spiral tube is welded by cutting two 1/4 round steel pipes. Three sections of electromagnetic coils and insulation layers are wound outside the reactor cavity to set different heating temperatures to ensure that the cracking temperature is stable while avoiding heat loss. The cross section of the reactor is shown in Figure 3.
3.2. Parameter determination

The double helix is the core component of the whole reactor. The parameters of the helix will determine the reactor geometry and cracking capacity.

3.2.1. Relationship between reactor cracking capacity and spiral parameters. The calculation formula for the cracking treatment capacity of the reactor can be expressed as equation (1).

\[ Q = 47D^2Sn\lambda\epsilon \]  
(1)

Among them, \( Q \) is the cracking treatment capacity of waste plastic, t / h; \( D \) is the outer diameter of the spiral, m; \( S \) is the pitch of the spiral, m; \( n \) is the speed of the spiral, r / min; \( \lambda \) is the mass per unit volume of the material, t / m\(^3\); \( \phi \) is the material filling factor; \( \epsilon \) is the inclined conveying coefficient.

It can be seen from equation (1) that the waste plastics cracking treatment capacity is related to parameters such as the spiral outer diameter, pitch, spiral speed \( n \), and filling factor [5].

3.2.2. Spiral speed. The rotation speed of the spiral in the reactor directly affects the residence time of the waste plastic in the cavity, and then affects the cracking treatment capacity of the waste plastic. For the stress analysis of the waste plastic while it is moving in the reactor, the centrifugal force must be less than the gravity of the material itself. The maximum centrifugal force of the material is \( m\omega^2_{\text{max}} \) and the gravity is \( mg \). The relationship is:

\[ m\omega^2_{\text{max}} \leq mg \]  
(2)

\[ 2an_{\text{max}}r / 60 \leq \sqrt{gr} \]  
(3)

Considering the impact of waste plastics in different states

\[ an_{\text{max}}r / 30 \leq k\sqrt{gr} \]  
(4)

\[ n_{\text{max}} = \frac{30}{\pi} \sqrt{\frac{g}{r}} = \frac{30k}{\pi} \sqrt{\frac{2g}{D}} \]  
(5)

Among them, \( K \) is the comprehensive coefficient of material; \( n_{\text{max}} \) is the maximum speed of the spiral, r / min; \( g \) is the acceleration of gravity, m / s\(^2\); \( D \) is the outer diameter of the spiral, m; \( r \) is the radius of circular motion of the material, m.

Make \( A = 30K\sqrt{2g / \pi} \)

\[ n_{\text{max}} = A / \sqrt{D} \]  
(6)
Among them, $A$ is the comprehensive characteristic coefficient of the material.

3.2.3. Pitch and screw shaft diameter. The pitch is the shortest axial distance between the corresponding points between adjacent spiral blades. It determines the size of the spiral rise angle and affects the transportation of waste plastic in the reactor. The calculation formula of the pitch is:

$$S = K_d D$$

(7)

Among them, $K_d$ is the proportionality factor between the pitch and the diameter of the spiral blade [5].

$$d = (0.2 \sim 0.35) D$$

(8)

3.2.4. Spiral outer diameter.

$$Q = 47K_A \phi \lambda D^{5/2}$$

(9)

$$D = \left( \frac{Q}{47K_A \phi \lambda} \right)^{2/5}$$

(10)

3.2.5. Actual calculation. Designed cracking capacity = 0.3t / h. By querying the comprehensive characteristic coefficient table [5], it can be obtained that the material comprehensive coefficient $K = 0.049$, the material comprehensive characteristic coefficient $A = 50$, and the material filling coefficient $\phi = 0.35$. The density of the mixed waste plastic is set to $\lambda = 0.9t / m^3$.

Bring the known data into equation (11), perform calculations, take an integer, and determine that $D = 0.4m$. Let $K_a = 0.3$ [6] and calculate the pitch $S = 0.12m$ according to equation (7). Bringing the above data back to equation (1), the spiral speed as $n = 6.375r / min$ can be obtained, and rounded to determine $n = 6r / min$. In addition, the effective working length of the reactor is calculated as $L = 7.5m$. In order to ensure the stable forward transportation of waste plastic in the reactor, full heat exchange is performed to achieve rapid and complete cracking. On the circumference of the continuous spiral blade, a triangular groove is opened every $60^o$, and its geometric size is shown in Figure 4.

![Figure 4. Cross section of the spiral](image)

4. Simulation and strength check

When the waste plastic is spirally conveyed in the reactor, the edge of the spiral is first heated and has the highest temperature. After the model is imported into the finite element analysis software workbench, the mesh is divided and the temperature is loaded. The temperature distribution and thermal stress distribution of the spiral blade are shown in Figure 5 and Figure6. It can be concluded from Figure 5 and Figure6 that the maximum value of the spiral thermal stress is 14.1 MPa. According to the allowable
stress table of steel [7], the allowable stress of the metallic material 321 alloy steel at 600 °C is 44 MPa, which meets the requirements for use.

5. Conclusion

According to the characteristics of waste plastics in domestic waste, a design scheme for cracking waste plastics using electromagnetic cracking heating and a double spiral meshing propulsion structure was proposed, and calculation and simulation analysis were performed. The designed spiral waste plastic cracking reactor has the advantages of enabling forced transportation, sufficient stirring, anti-coking, energy saving. It can realize continuous industrial cracking of waste plastics, and has broad prospects for promotion and application.

References

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