Study on the Harm of Waste Activated Carbon and Novel Regeneration Technology of it

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Abstract. Activated carbon is widely employed as an adsorbent in environmental protection, food, medicine, chemical industry, energy and other fields due to its good physical and chemical properties and low price. However, the resulting large amount of saturated activated carbon is easy to release harmful substances in the high temperature environment. Even if the saturated activated carbon is treated with harmless regeneration technology, it may lead to secondary pollution owing to improper disposal. Therefore, on the basis of summarizing the traditional methods of activated carbon regeneration, combined with the research progress in the laboratory, frontier progress of new activated carbon regeneration technology are elaborated in recent years in this paper, and the development direction of activated carbon regeneration technology are also presented in the end of the paper.

Keywords: adsorbent, saturated activated carbon, activated carbon regeneration, secondary pollution.

1. Introduction
Due to the developed pore structure, ultrahigh specific surface area, stable chemical stability and strong adsorption capacity, activated carbon (AC) was widely applied to toxic and harmful gas, pollution water treatment, which was known as "penicillin" of environmental pollution control. But the service life of AC was short, once the adsorption was saturated, it was easy to form secondary pollution under high temperature environment. [1] The harm of waste AC was mainly shown in the following three aspects:

1.1. Destruction to the ecological environment
With the development of industry, the hazardous waste in the process of industrial production is increasing day by day. The annual production of hazardous waste in China was 60 million tons, of which the waste AC accounted for about 65%. [2] China had shortcomings in the disposal of waste AC, which were mostly randomly stacked, simple landfill, without the corresponding safety measures, causing serious pollution to the surrounding groundwater, soil, surface water, atmosphere and so on. The non-standard incineration of AC would produce toxic and harmful gases and pollute...
the atmospheric environment. The incineration of chlorine-containing organics would even produce
dioxins and furan carcinogens, which would bring harm to human beings. Irregular landfills would
also pollute water sources and soil, especially heavy metals and highly toxic wastes could even cause
long-term harm.

1.2. Detriment to human health
Some toxic and harmful substances caused acute poisoning due to ingestion, inhalation or skin
absorption, which would directly affect human health and cause short-term harm to human body.
PM2.5, acid rain, fog and haze were all directly related to hazardous waste, which may cause toxicity
through ingestion, inhalation, skin absorption and eye contact, and repeated contact may even lead to
poisoning, carcinogenesis, teratogenicity and mutagenesis.

1.3. Constraints to the sustainable development of economy and society
The pollution of air, water and soil caused by non-treatment or non-standard treatment of hazardous
waste would also become the bottleneck restricting economic development activities. [3]
As a country with limited forestry resources, it is bound to cause the waste of non-renewable
resources in China if the waste AC was treated as solid waste or hazardous waste. Therefore, the
research of AC regeneration technology not only had engineering value and economic value, but also
would be of important practical significance for China's "strive to reach the peak of carbon emissions
before 2030 and achieve carbon neutrality before 2060" from the perspective of environmental
protection and economy.

2. Traditional AC regeneration technology
AC regeneration technology is to achieve the purpose of reuse of saturated AC through various
methods to restore its adsorption performance. The regeneration method mainly depends on the type
of AC and the nature of AC adsorbed substances. Traditional AC regeneration technology mainly
includes thermal regeneration method, chemical regeneration method, biological regeneration method,
microwave regeneration method and so on.

Table 1. Comparison of advantages and disadvantages of various traditional regeneration methods.

| Regeneration method       | advantages                                           | disadvantages                                                      |
|---------------------------|------------------------------------------------------|---------------------------------------------------------------------|
| thermal regeneration      | The application range is wide, the regeneration time is short, the regeneration efficiency is high | After regeneration, the loss of carbon is greater, the mechanical strength of renewable carbon is decreased, and the investment and operation costs are high |
| chemical regeneration     | Convenient operation and high efficiency             | High energy consumption, easy to cause secondary pollution, long regeneration time |
| biological regeneration   | Simple operation and low investment cost             | The regeneration time is longer, regeneration is easy to be affected by the water quality and temperature |
| microwave regeneration    | Short regeneration time, low energy consumption, high efficiency | In the process of regeneration, it is necessary to further study whether there are poisonous and harmful intermediates |

3. Novel AC regeneration technology
These traditional methods shown above are more or less deficient in the loss of regenerated carbon and
secondary pollution. In order to overcome the defects of traditional regeneration methods, novel AC
regeneration technologies have emerged in recent years.

3.1. Plasma regeneration method
Plasma regeneration technology refers to the accelerated electron movement in the high energy field to
make water molecules and other molecules jump to the excited state, and the waste AC would achieve
regeneration by those molecules to desorb pollutants adsorbed on the surface of it. Qu et al. combined
AC adsorption with dielectric barrier discharge (DBD) plasma technology for the removal of organic
pollutants that are difficult to degrade in water, and realized the degradation of organic matter adsorbed on AC by DBD plasma and the regeneration of AC by DBD plasma. [4]

Plasma regeneration technology can effectively avoid AC ablation. Meanwhile this method had following characteristics: high regeneration efficiency, no secondary pollution, short regeneration time, small AC loss and strong application. However, there are high energy consumption and defects in the reactor structure. [5]

3.2. Photocatalytic regeneration method
The photocatalytic regeneration method is to realize the in-situ regeneration of the adsorption material by means of mixing the photocatalyst with the adsorption material to produce the photocatalytic composite material. [6] The optimum conditions for the combined process of air stripping and photocatalysis were studied by Chen et al. with the AC saturated with toluene as the experimental object. Finally, it was proved that the combined process of air stripping and photocatalysis can effectively regenerate the saturated AC. [7]

The photocatalytic regeneration method has the advantages of simple regeneration process, free control of production scale and simple operation of equipment. However, the further development is limited by its long time consuming and low regeneration effect.

3.3. Supercritical fluid regeneration method
Supercritical fluid (SCF) regenerate the saturated AC by extracting organic matter with the application of supercritical fluid which had ultra-high solubility. Costa AE et al. produced SCF by ethanol and CO with a molar ratio of 1:3 at 14 MPa and 106-134°C. The regeneration of the resin adsorbed with glycerol can be completed in 4.17min. [8] USHIKI I et al. analyzed the organic compounds on the saturated AC and drew a conclusion that the main factors affecting the regeneration of AC were the physical and chemical properties of organic compounds, especially the vapor pressure of volatile organic compounds and the affinity of adsorbents. [9]

SCF generally have super solubility, good solubility, high mass transfer rate excellent diffusion performance, small surface tension and other characteristic. The disadvantage of this method is that the requirements of technology and equipment are relatively high, and the investment cost is large. [10]

3.4. Ultrasonic regeneration method
Ultrasonic regeneration method is to rely on the frequency of ultrasonic wave (wavelength between 0.01 ~ 10cm) to produce "cavitation bubble" with enormous energy. At the moment when the “cavitation bubble” bursts, the surrounding liquid suddenly bursts into the bubble, resulting in local high temperature and high pressure. The maximum temperature and pressure generated can be expressed as:

\[
T_{\text{max}} = T_0 \left( \frac{P_m(k-1)}{P} \right) \quad (1)
\]

\[
P_{\text{max}} = P_0 \left( \frac{P_m(k-1)}{P_0} \right)^{\frac{k}{k-1}} \quad (2)
\]

Where \(T_0\) is the ambient temperature of the liquid, \(P_m\) is the total pressure acting on the outer surface of the bubble, while \(P_0\) is the vapor pressure inside the bubble, and \(K\) is the specific heat ratio of the vapor. [11]

It can be concluded from theoretical calculation that the temperature, pressure and temperature change rate of the local area can be reached 5000K, 10MPa, 1010K/s, respectively. And the adsorbed material could be peeled off the surface of saturated AC under the influence of tremendous energy.
Yang et al. adopted microwave, ultrasonic and microwave-ultrasonic methods to regenerate saturated AC containing Cr in the electroplating industry. The experiment showed that the recovery rate of AC could reach 99.93% when the wave power was 640 W, the microwave time was 6 min, the ultrasonic liquid pH was 1 and the ultrasonic time was 75 min. [12]

Ultrasonic method is suitable for regenerating the AC after physical adsorption, which has good energy saving and small carbon loss. But its regeneration efficiency is not stable, and the development of sonochemical reaction equipment is still at the bottleneck stage.

4. Conclusions
At present, the comprehensive utilization of AC has been widely used in various fields of China's national economy, with a wide application range and large amount. With the wide employment of AC, the comprehensive treatment of saturated AC had been further developed. Although the above AC regeneration technology had achieved a good regeneration effect in the laboratory research, which still could not be applied to large-scale production due to the harsh experimental environment, and the regeneration effect of only using a single regeneration method to resolve the adsorbents on the surface of AC is not ideal.

Therefore, the coupling of the two or a variety of technologies can be used for processing, such as the combination of chemical regeneration method and ultrasonic technology. The advantage of ultrasonic regeneration is low energy consumption, while the deficiency is low yield of regenerated AC; Chemical method has the advantage of high regeneration efficiency, still has the very high adsorption efficiency after many incarnations, but deficiency is the energy consumption is higher. if these two methods mentioned above could be applied in combination , the problems of other renewable technology that is difficult to overcome can be solved, and this will greatly increase the rate of activation of AC. [13] Therefore, the author believes that the combined treatment of both or multiple technologies is likely to become a research hotspot in the future.

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