

Methods and Improvement Measures Based on Solar Panel Recycling

Yuxuan Sun

College of Energy and Power Engineering, Inner Mongolia University of Technology, Hohhot, China

202310308092@imut.edu.cn

Abstract: Although solar energy is the second largest source among new energy options, it faces challenges such as limited lifespan, environmental pollution, and significant difficulties in recycling and reuse. This paper systematically expounds the principles and recovery processes of the physical method, chemical treatment method, and microbial method, dialectically analyzes the advantages and disadvantages of traditional recovery methods and optimized recovery methods, and introduces the frontier research of related recovery methods. Through the analysis of these methods and cutting-edge research, it is found that these methods have certain complementarity in the recycling process and the advantages and disadvantages of recycling and can be comprehensively applied to recycling solar panels, but this direction is not paid attention to at present. Therefore, based on the comprehensive application of the physical method and chemical treatment method, this paper innovatively proposes a new, improved method. This method uses the whole glass separation process and salt etching method, which not only ensures the complete recovery of the solar panel glass and junction box but also recovers the valuable metals with high purity. Through the analysis of its technology, economy, and environment, it is proved that this method has certain application value.

Keywords: Solar panel, Recycling method, Improvement summary

1. Introduction

With the overuse of traditional fossil energy and the increasing demand for energy, the earth's environment is deteriorating, and traditional fossil energy is drying up. However, the development and utilization of renewable energy has become the key to solving this problem. Solar energy plays an important role in renewable energy. However, after the service life of solar panels has exceeded, the problem of recycling and reusing solar panels has become prominent. The recycling of traditional solar panels has many problems, such as low efficiency, complex process, high cost, large environmental pollution, and so on, which require researchers to develop cleaner, simpler, cheaper, and more efficient methods.

For the recycling and utilization of solar panels, some progress has been made in the physical method, chemical treatment method, and microbial method. In the physical method, Xiao et al. Successfully recovered a variety of materials in perovskite solar cells through the overall recovery strategy of green solvent and the recovery method of water-based perovskite [1]. This method not only reduces the cost of large-scale application but also improves the recovery purity of perovskite.

However, in small-scale applications, the problems of high cost and solvent treatment still need to be solved. Padamnath and others can flexibly treat waste solar panels by using electro-hydraulic crushing technology, and they will not produce toxic waste gas and wastewater [2]. However, there is still room for improvement in equipment costs and operational safety. In the chemical method, Zant et al. Recycle the solar panel metal by using the aluminum chloride-ferric chloride solution method, which has high purity and does not produce toxic waste [3]. However, the cost of chemical reagents still needs to be solved. In the microbial method, the application of recycling solar panels is still in the theoretical stage. At present, kakankar beads and others have found that *Penicillium chrysogenum* has the best fermentation effect, mild conditions, high metal recovery rate, and the potential to recycle waste solar panels [4]. Microbial culture conditions and stability are still restricting the application of industrialization.

To sum up, this study summarizes the methods of recycling solar panels in order to explore a more effective method.

2. Methods of recycling solar panels

2.1. Physical method

The physical method mainly uses physical methods such as mechanical force to separate or decompose components and realize effective recycling of materials. At present, physical methods are mainly divided into mechanical crushing methods and physical separation methods.

The mechanical crushing method first separates the aluminum frame of the solar panel and then uses a variety of crushing equipment, such as a cutting machine, pulverizer, crusher, etc., to further crush the solar panel. The contact area of the broken solar panel becomes larger, and many materials inside the solar panel can be exposed to separate and decompose. In Amjad Ali et al. Introduced the mechanical recovery process in their article. The mechanical crushing method mainly follows the process of disassembly, decomposition, particle size reduction, screening, dense medium separation, material recovery, and integration into the production cycle [5]. Among them, the traditional mechanical crushing method has a simple structure and low cost, but the recovery efficiency is not high, and the recovery purity is low. The optimized mechanical crushing method uses more advanced instruments and equipment than the traditional mechanical crushing method and pays more attention to the role of shearing in the process of particle size reduction so that the fine particles of solar panels are more uniform. In addition, in the screening process, more attention is paid to the use of the physical properties of broken solar panels to improve the separation effect. Although this method improves the recovery purity, the cost will also increase a lot. According to the existing scientific research, the change of the physical properties of solar panels by using liquid nitrogen in the mechanical crushing method can significantly reduce the adhesive film viscosity of solar panels and improve the removal rate of glass and the enrichment degree of silicon [6].

The physical separation method mainly uses the physical properties of substances, such as density, magnetism, conductivity, and other differences, to achieve separation. Among them, the physical separation method mainly follows the process of preliminary disassembly, glass separation, crushing, screening and magnetic separation, electrostatic separation, collection, and subsequent processing. Traditional physical separation methods focus on precise physical separation equipment. Although this method has relatively good recovery efficiency and purity, its structure is slightly more complex and costly compared to mechanical crushing methods. The optimized physical separation method breaks the traditional physical separation method's demand for precision separation instruments and instead focuses on the physical properties of the broken solar panels. As long as the physical properties of the solar panels at the time of breakage are known, they can be directly used for recycling. The optimized physical separation method can not recycle glass and other materials well and still has

some disadvantages in resource reuse. According to scientific research, the whole glass separation process softens EVA material by heating and uses tools such as heating stripping knives to separate the glass of solar panels with high precision, and the separated glass can be directly put into secondary use [7]. This method has high recovery accuracy and realizes partial material closed-loop. For the physical separation method using high-pressure pulse crushing technology, the double glass module is placed in the high-pressure pulse crusher and then placed in the quartz tube after treatment. The outer side is treated by an EVA thermal decomposition reactor in the high-temperature tubular furnace, and finally, the metal impurities are removed to complete the recovery [8]. Although the recycling degree of glass is lower than that of the former, it can better recover metal with low cost and is expected to be commercialized.

2.2. Chemical treatment method

The chemical treatment method mainly uses various chemical reagents to purify some effective metals and make them recycled. The chemical treatment in this method mainly follows the process of primary separation, chemical treatment, purification treatment, metal recovery, silicon material treatment, and wastewater treatment. Although the traditional chemical treatment method can effectively separate materials and improve resource recovery, it will produce toxic gases or toxic solutions, which will also have a great impact on the performance of materials. The essence and principle of the optimized chemical treatment method are still consistent with the traditional chemical treatment method, but in actual use, the optimized chemical treatment method uses more high-quality chemical reagents and uses ultrasonic and other methods to improve its reaction rate, which solves the big problem of toxic gas emission. However, this method still has a certain impact on the performance of recycled materials, and the high reagent cost also restricts its application.

At present, the salt etching method studied by Gao and Chen et al. Separates silver and aluminum metals from silicon wafers through the reaction characteristics of molten NaOH-KOH with SiN_x , SiO_2 , Al_2O_3 , and Si, and then oxidizes the solder strips containing copper, tin, and lead from the air and then dissolves them into NaOH. Finally, lead and tin are recovered from NaOH by electrodeposition [9]. The process of this method is relatively simple and has strong applicability. It is not only suitable for the traditional AI-BSF battery but also suitable for the current mainstream PERC and top con silicon battery and other battery structures. In the recycling process, no toxic waste is generated, and the whole process also realizes the material closed-loop. The high-purity recycled materials can be used in many fields. However, the high cost of chemical reagents makes it difficult to apply this method on a large scale.

In addition, the aluminum chloride ferric chloride solution method studied by Zant et al. first places solar cells in an aluminum chloride solution and uses ultrasonic waves to promote aluminum dissolution, and then uses ferric chloride to dissolve silver in choline chloride or calcium chloride brine in the solar cells, in order to recover metals inside the solar panels [3]. The brine used in this method exists in the feed of chickens and the gravel used for road deicing in winter, which is very common and easy to obtain, reducing the cost of brine and is non-toxic. At the same time, it does not affect the performance of nitride antireflective coating and silicon wafer, which makes it possible for the silicon wafer to be reused and used for other purposes. However, the subsequent extraction of aluminum and silver by this method requires further treatment to become high-purity metals, which increases the cost of this method. The application of this method in the laboratory is also slightly difficult in the industrialization. For example, ferric chloride and aluminum chloride solutions are actually faced with a large number of solar panels, so it is difficult to ensure that each panel can be evenly contacted with these reagents. The processing speed in the reaction process also makes it difficult to meet the needs of large-scale recovery.

2.3. Microbial method

The microbial method mainly uses microorganisms to produce specific enzymes to decompose materials. At present, this method is still in the exploratory stage, and the two methods that are expected to be applied to the recovery of solar panels are the microbial adsorption method and the microbial leaching method.

The microbial adsorption method mainly uses the functional groups on the surface of bacteria, which can be combined with metals to recover solar panels. The microbial leaching method is to use the metabolites produced by microorganisms such as *Acidithiobacillus ferrooxidans* in the metabolic process, which can react with the metal in the solar panel to make the metal enter the solution in the form of ions, so as to realize the recovery. These two methods have mild conditions, strong selectivity, and good persistence but low efficiency, harsh culture conditions, and poor stability.

At present, Gao et al. have confirmed that the new BEMFC can be used to recover valuable metals from heavy metal wastewater and obtain bioelectricity from it [10]. This method mainly uses the electricity-producing bacteria at the anode to decompose the organic matter, and the decomposed organic matter turns into carbon dioxide to produce electrons and protons. Then the electron to the cathode combines with the heavy metal of the electron acceptor, and the heavy metal ions are finally converted into simple substances and generate current. This technology is green and efficient and has a strong application prospect in the treatment of heavy metal wastewater.

There are also some valuable heavy metals in solar panels, which have the possibility of recycling by using this technology, but it still needs some improvement before use. In addition, Seturajan and others have achieved the recovery of key raw materials from secondary resources through the study of bio/Hydrometallurgy [11]. This method needs to cultivate microorganisms and prepare appropriate leaching agents according to the types of recycled raw materials, and then mix the specially treated secondary resources with the cultivated microbial bacterial solution and leaching agents to leach under the conditions of appropriate microorganisms. After leaching, metal ions are separated and enriched from the leaching solution by ion exchange and electrodeposition, and high-purity metal is finally obtained. This method is environmentally friendly, produces less waste than the traditional metallurgical method, and has higher selectivity, which can also reduce the introduction of impurities. However, the longer treatment cycle and the adaptation of microorganisms will also affect the recovery effect. For solar panels, microbial culture can be carried out according to the specific metal in the solar panel, supplemented by an appropriate leaching agent to recover the solar panel.

3. Improvement of solar panel recycling method

3.1. Improvement method and principle

Traditional research is focused on a single category of research, using a variety of materials and other methods to improve the efficiency of recycling solar panels and the purity of recycled metal. The three methods described above have unique advantages and disadvantages. For example, the physical method can separate the outer part of the solar panel with high precision, but it cannot recover the high-value metal inside with high purity. High purity value metals are recovered by chemical treatment methods, but it is difficult to use them externally. The microbial method has strong selectivity and mild conditions, but there is still much room for development in terms of processing speed and capacity. Therefore, when these three categories of methods are linked together, they make up for each other's shortcomings and combine with the relatively mature and stable methods of predecessors. The recycling effect of solar panels may be improved.

Based on this, the improved method is preliminarily based on the comprehensive application of the physical method and chemical treatment method to recover solar panels. The solar panel is mainly

composed of tempered glass, EVA adhesive film, battery, back plate, aluminum alloy frame, junction box, and silica gel. In Zhai et al.'s patent, the above solar panel parts are defined as laminates, junction boxes, and aluminum frames [7]. For the convenience of narration, this definition will be used here. For the physical method, in order to completely recover the whole solar panel for application, the physical separation method is selected here. Compared with the mechanical crushing method, this method can recover the separable parts, such as the aluminum frame and junction box, without affecting the performance of the material. The remaining part is mainly composed of battery panels containing various valuable metals. In order to recover these valuable metals, the chemical treatment method will be used here. Compared with the microbial method, the chemical treatment method has more relaxed conditions and high purity, which is more conducive to industrial production. The principle of this method is to use the physical separation method to separate and recover the junction box, aluminum frame, glass and other materials of the solar panel with high precision, and then use the chemical treatment method to recover the aluminum, silver and other metals in the solar cell with high purity, so as to realize the complete recovery of the solar panel.

3.2. Improvement effect

In the physical separation method, in order to ensure the integrity of recycled materials, the better recovery methods are the double glass physical treatment process and the whole glass separation process. In the double glass physical treatment process, Fan et al. Recycle solar panels by using a single container double glass on-site recycling equipment, which consists of containers, loading devices, junction box removal devices, and glass removal devices. The front glass removal unit and back glass removal unit in the glass removal device can handle double glass components, which is highly practical [12]. Although this method is practical, the separation effect is also very good. However, the glass cannot be recycled completely and needs secondary treatment. For the whole glass separation process, this method can directly recycle the glass for secondary use. Therefore, in order to achieve the material recycling of the whole solar panel, the latter has more advantages than the former in the selection of physical separation measures, which increases the material utilization rate of this improved method. In the whole glass separation process, first disassemble the junction box and aluminum frame. Then, according to the data measured by Zhai et al., the glass with an average area of 15 square centimeters can be recovered with a 100% recovery rate under the conditions of 30% weight fraction, 75 °C soaking temperature, and 30 minutes soaking time [7]. By using this condition, the glass part in the aluminum frame and laminate of the junction box can be completely recovered.

The remaining part is mainly composed of valuable metals. Using the salt etching method, it can achieve a recovery rate of more than 99% for silver and more than 98% for silicon in only 180 seconds without using toxic mineral acids and generating secondary pollution. After that, Cu, Pb, and Sn can be recovered from solder strips by oxidation, alkali leaching, and electrochemical deposition [9]. Finally, the high-purity collection of valuable metals is realized.

To sum up, this improved method combines the whole glass separation process and salt etching method to completely recover the glass part in the junction box, aluminum frame, and laminate of the solar panel, and the remaining value metal is recovered with high purity. In order to take a more comprehensive view of the feasibility of this method, we will evaluate it from three aspects: technology, economy, and environment. Technically, these two methods have been tested and verified by predecessors, and the feasibility of this improved method has been proved. Economically, professional equipment and specific chemical reagents such as salt solution can recycle all kinds of valuable materials, which is feasible on the basis of controlling the cost. In terms of environment, according to LCA life cycle emission analysis, this method has advantages in the resource reuse and recovery stages and has good environmental benefits.

4. Conclusion

With the development of the times, a large number of applications of solar panels are the general trend, so the low-cost and efficient recycling method is very critical. To sum up, the physical method mainly uses physical methods such as mechanical force to separate or decompose components; the Chemical treatment mainly uses various chemical reagents to purify some effective metals; the Microbial method mainly uses microorganisms to produce specific enzymes to decompose materials. Compared with the traditional three methods, the optimized physical method and chemical treatment method can improve the recovery purity and efficiency by increasing the cost, while the optimized microbial method can improve the recovery effect, but it still needs to be developed. Therefore, based on the comprehensive application of the physical method and chemical treatment method, this paper innovatively proposes a new, improved method. This method uses the whole glass separation process and salt etching method, which not only ensures the complete recovery of the solar panel glass and junction box but also recovers the valuable metals with high purity. Through the analysis of its technology, economy, and environment, it is proved that this method has certain application value. In the future, this improved method can improve the process of recycling solar panels, thereby reducing costs. This paper summarizes and analyzes the main recycling methods of solar panels and puts forward better methods for the recycling of solar panels.

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