Analysis of the cleaner production level of a printing plate roller factory in north China and improvement schemes

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Abstract. The improvement of the cleaner production in the enterprises can not only achieve the source control of pollution and the efficient use of resources, but also strengthen their comprehensive competitiveness. It can also help to realize China’s environmental protection goal. In this paper, a printing plate roller factory in northern China is taken as the research object. The evaluation index system for the cleaner production level of the printing plate roller industry is constructed based on the relevant national standards of cleaner production in the mechanical processing industry and the electroplating industry. The Analytic Hierarchy Process is used to determine the weight of each evaluation index. The evaluation model will be established to evaluate the factory’s cleaner production status and improvement schemes will be put forward.

1. Introduction

With the advancement of China's urbanization process, the demand of resources is growing with each passing day, but the excessive use of resources has also brought about serious environmental problems. In order to reduce the consumption of resources and the generation of pollutants as well as promote the sustainable development of the national economy, China is actively calling for companies to push forward cleaner production.

Cleaner production originated in the United States and has been widely promoted by the United Nations [1]. Cleaner production has developed rapidly both at home and abroad as a comprehensive preventive environmental protection strategy. There are researches of the cleaner production on electroplating industry, mechanical industry, mining industry, pharmaceutical industry and so on. However, most research methods can only be used for a single industry. And the researches for the printing roller industry are very few now, besides, there is no national standard for the printing roller industry yet. So this article will first establishing corresponding clean production evaluation index system, then determining evaluation index standards by referring the national standards of the electroplating industry and the mechanical processing industry, next, analysing their weight values, evaluating the cleaner production level, and finding the most suitable clean production plan.

2. Cleaner production theory

2.1. Definition of cleaner production

The definition of cleaner production has experienced a complex process, and there are many documents can be referred, such as Cleaner Production Programme, Agenda 21, International Cleaner
Production Declaration, People's Republic of China Clean Production Promotion Law and so on. In summary, cleaner production refers to unceasingly adopting better methods, such as: improvement of design, use of clean energy and raw materials, adoption of advanced process technologies and equipment, improvement of management, comprehensive utilization and so on, so as to reduce pollution from the source, make full use of resource and reduce or dismiss the pollution discharged during the process of production, services, and usage. Besides, it also aims to reduce or eliminate the harm to human health and environment [2].

2.2. Cleaner production evaluation steps
The basic connotation of cleaner production can be summarized into the following three aspects: the use of clean raw materials and energy, clean production processes and clean products [3]. In general, the cleaner production level evaluation includes the following steps. First, we need to construct the cleaner production evaluation index system for the industry, which includes the construction of the evaluation index system framework and the primary selection as well as second screening of evaluation indicators [4]. Next, the evaluation index weights and evaluation criteria need to be determined. Then, define the enterprise’s cleaner production level by use of the determined evaluation criteria and evaluation model. Finally, analyses out the main factors that restrict the cleaner production level of the production, then proposes reasonable improvement methods and judge its feasibility.

2.3. The production status of the printing plate roller factory
The factory locates in Harbin, having 85 employees and the production shop includes a machine shop and a plate-making shop. The machine shop mainly uses steel plates or steel pipes to produce steel pipe rollers by mechanical processing. The plate making shop mainly produces finished gravure plate rollers by surface plating and electric carving.

2.3.1. Consumption of raw materials and auxiliary materials. The main raw materials used in the printing roller industry are seamless steel tubes and steel plates, copper balls, nickel plates and nickel sulfate, and chromic anhydride (chromium trioxide). In addition to raw materials, this enterprise also use sulfuric acid and sodium hydroxide as auxiliary materials. The loss of material are mainly caused by the impurities in raw and auxiliary materials, improper controlling of the plating process, and equipment sealing problems.

2.3.2. Consumption of energy and water. The total electricity consumption is 1001322 kWꞏh, and the power consumption of the plate making workshop was 499,021 kWꞏh; the power consumption of the machine shop was 415,170 kWꞏh. The energy consumption mainly comes from the equipment in the workshop, which has a great potential for saving electricity. The power loss is mainly due to problems such as low pump efficiency, high voltage of electroplating power supply, and improper corporate management.

The water consumption of this project mainly comes from three parts: production, daily life and boiler house. The enterprise’s water consumption is about 22.21 t/d. The loss of water is mainly due to improper control of the plating process and untight sealing of the equipment. The electroplating waste water generated has great impact on the environment.

3. Analysis of cleaner production level of the printing plate roller enterprise
3.1. Construction of evaluation index system
Since there are no cleaner production standards for the production of printing plate rollers, we take the cleaner production standards of the mechanical processing industry and electroplating industries as references. Through the preliminary selection and second screening of indicators, the cleaner production evaluation index system and the cleaner production evaluation standards applicable to the printing plate roller industry are finally determined. The AHP is used to determine the weight value of
each evaluation index [5], and the single factor index evaluation model is used to evaluate the cleaner production level of the enterprise [6]. Finally, the results will be compared with the evaluation criteria, which can reflect the cleaner production level of the enterprise intuitively and quantitatively.

3.1.1. The Construction of evaluation index system. The evaluation index system should be integrity, effectiveness, and evaluability. Integrity means the evaluation index system should cover the main aspects of the research object as much as possible; effectiveness means the selected evaluation indicators are mutually independent and there is no duplication; evaluability means the selected evaluation index can be quantified as much as possible and easily obtained [7]. The framework of the evaluation index system for cleaner production is shown in Figure 1.

![Figure 1. Framework of evaluation index system for cleaner production Level.](image)

3.1.2. The primary selection of evaluation indicators. The enterprise mainly produces intaglio roller, which has no corresponding cleaner production standards. Intaglio roller manufacturing involves mechanical processing and electroplating, so we can refer to the "Cleaner Production Evaluation Index System for the Machinery Industry (Trial)" and the "Cleaner Production Evaluation Index System for Electroplating Industry ", and then a total of 34 evaluation indicators are obtained from the preliminary selecting results.

The 34 indicators are divided into quantitative indicators and qualitative indicators so that it can be understood and calculated easily. Those two types indicators will be evaluated separately, and their scores will be both included in the assessment results at last. The preliminary selecting results of qualitative indicators and quantitative indicators for cleaner production in the printing plate roller industry are shown in Figure 2 and Figure 3 respectively.

![Figure 2. The preliminary selection results of qualitative indicators.](image)
3.1.3. Second screening of the evaluation index. The second screening of evaluation indicators need to follow the principle of accessibility, representation, conciseness and quantitative [7]. After the second screening, only 15 indicators are left. The evaluation criteria are based on the first-grade evaluation criteria in the "Cleaner Production Evaluation Index System for the Machinery Industry (Trial)" and "Evaluation Index System for Cleaner Production in the Electroplating Industry" issued by the State. The quantitative indicators and evaluation criteria are shown in Table 1. The qualitative indicators and evaluation criteria are shown in Table 2.

3.2. Determination of the indicators’ weight and evaluation criteria. This paper adopts the Analytic Hierarchy Process (AHP) to determine the weights, which compares the relative important degree of the indicators, and assigns the weights to them respectively. The AHP can be divided into five steps [8].

The weight vector calculated is: \([0.12, 0.08, 0.10, 0.06, 0.05, 0.04, 0.05, 0.09, 0.09, 0.04, 0.05, 0.08, 0.04, 0.06, 0.05]^T\). The weight values of different evaluation indexes are determined according to the weight vector, as is shown in Figure 4.

Table 1. Quantitative indicators and evaluation criteria.

| Number | Index Layer                                                                 | Unit     | Criteria |
|--------|----------------------------------------------------------------------------|----------|----------|
| 1 (P1) | The Utilization Rate of Copper                                           | %        | ≥90      |
| 2 (P2) | The Utilization Rate of Nickel                                            | %        | ≥95      |
| 3 (P3) | The Utilization Rate of Chromium                                         | %        | ≥90      |
| 4 (P4) | Fresh Water Consumption for per 10,000 yuan Worth of Industrial Added Value | t/10,000 | 18.48    |
| 5 (P8) | Steel Consumption for per 10,000 yuan Worth of Industrial Added Value     | t/10,000 | 0.56     |
| 6 (P6) | Electroplating Wastewater Treatment Rate                                  | %        | 100      |
| 7 (P9) | The Reuse Rate of Water in the Whole Factory District                    | %        | 60       |
| 8 (P11)| The Amount of Discharged Waste Solid per 10,000 yuan Worth of Industrial Added Value | t/10,000 | 0.12     |
Table 2. Qualitative indicators and evaluation criteria.

| Number | Index Layer                          | First-grade Evaluation Criteria                                                                 |
|--------|--------------------------------------|--------------------------------------------------------------------------------------------------|
| 1 (P7) | Water Saving Facilities              | Adopting the water metering devices and online water recycling facilities.                      |
| 2 (P12)| Requirement for Electroplating Production Line | The implementation of the energy-saving measures; automated or semi-automated situation of the production lines. |
| 3 (P5) | Environment Emergency Response Plan  | Draw up a complete environmental emergency response plan and conduct environmental emergency drills. |
| 4 (P10)| Implementation of Industrial Policies| Correspond with national and local industrial policies                                             |
| 5 (P13)| Hazardous Waste Treatment           | GB 18597 and other relevant regulations                                                         |
| 6 (P14)| The Implementation of “Three Simultaneous” | Projects which fails to meet the requirement of “Three Simultaneous” will be given no credits. |
| 7 (P15)| Prevent Measures for Hazardous Waste| The recycle of electroplating sludge and liquid wastes; prepare the hazardous waste transfer list in transfer. |

Figure 4. The Weight Values for the Evaluation Indicators.

3.3. Evaluation model

3.3.1. The evaluation model of comprehensive evaluation index. In order to evaluate the cleaner production level of the enterprise, not only quantitative indicators and qualitative indicators should be evaluated, but the final scores of these two types of indicators should be given different weights for comprehensive consideration, and then the comprehensive evaluation index (P) for the cleaner production level of the enterprise will be obtained.

The formula to calculate the comprehensive evaluation index is shown as follows:

\[ P = \alpha \cdot P_1 + \beta \cdot P_2 \]

- \( P \) — comprehensive evaluation index
- \( \alpha \) — the weight value of quantitative indicators—0.8
- \( P_1 \) — the total score of each secondary index in the quantitative evaluation index
- \( \beta \) — the weight value of qualitative indicators—0.2
- \( P_2 \) — the total score of each secondary index in the qualitative evaluation index
3.3.2. The evaluation of quantitative indicators in index layer. The formula to evaluate the quantitative indicators in index layer is that:

\[ P = \sum_{i=1}^{n} S_i \cdot K_i \]

- \( P_1 \) — the evaluate results of quantitative indicators
- \( n \) — the number of quantitative indicators
- \( S_i \) — the evaluation number of the \( i \)-th evaluation indicator
- \( K_i \) — the weight value of the \( i \)-th evaluation indicator

The formula for indicators with high scores and high cleaner production level is that:

\[ S_i = \frac{S_{xi}}{S_{oi}} \]

The formula for indicators with low scores but has high cleaner production level is that:

\[ S_i = \frac{S_{oi}}{S_{xi}} \]

\( S_i \) — the single-item index result of the \( i \)-th indicator ranges from 0 to 1.2, that is \( S_i \leq 1.2 \);

\( S_{xi} \) — the real value of the \( i \)-th indicator

\( S_{oi} \) — the standard value of the \( i \)-th indicator

3.3.3. The evaluation of qualitative indicators. We just evaluate "yes" or "no" and its effects when assessing the qualitative indicators, and the formula is:

\[ P_2 = \sum_{i=1}^{n} F_i \]

- \( P_2 \) — the evaluate results of qualitative indicators
- \( F_i \) — the score of the \( i \)-th indicator in index layer
- \( n \) — the number of qualitative indicators

3.3.4. Determination of the cleaner production evaluation standards. This study will classify the cleaner production level into four levels, that is, the international advanced level, the domestic advanced level, the general level and the low level. And the cleaner production level of the enterprise is determined by the comprehensive evaluation index value.

The evaluation grade is finally confirmed by considering the current situation of the practical production of the printing plate roller industry in China, and referring to the cleaner production evaluation standards of the mechanical industry and electroplating industry. As is shown in the cleaner production evaluation standards, 0.92 is the critical value of the international advanced level and the domestic advanced level in the cleaner production standards of the machinery industry. 0.85 is the critical value of the domestic advanced level and the general level of the cleaner production standard of the electroplating industry. Taking those two critical values into consideration, the cleaner production level of the printing plate roller manufacturing industry can be classified into 4 levels, and the comprehensive evaluation index of different evaluation levels in the printing plate roller industry is shown in Table 3.

| Sequence Number | Cleaner Production Level                | Comprehensive Index |
|-----------------|----------------------------------------|---------------------|
| 1               | The International Advanced Level       | \( \geq 0.92 \)    |
| 2               | The Domestic Advanced Level            | 0.85-0.92           |
| 3               | The Domestic General Level             | 0.60-0.85           |
| 4               | The Domestic Low Level                 | \( \leq 0.60 \)     |
3.4. Determination of the enterprise’s cleaner production levels

The cleaner production indicators of this enterprise is shown in Table 4.

| Indicators                                         | Weight Value | Evaluation Criteria | Current Score | Si-value | P-value |
|----------------------------------------------------|--------------|---------------------|---------------|----------|---------|
| The utilization of Copper                          | 0.12         | 90                  | 81.36         | 0.904    |         |
| The utilization of Nickel                          | 0.08         | 95                  | 89.87         | 0.94     |         |
| The utilization of Chromium                        | 0.10         | 90                  | 79.36         | 0.88     |         |
| Fresh water consumption per 10,000 yuan worth of   | 0.06         | 18.48               | 9.97          | 0.54     |         |
| industrial added value                            |              |                     |               |          |         |
| The treating rate of electroplating water          | 0.04         | 100                 | 100           | 1        |         |
| Steel consumption per 10,000 yuan worth of         | 0.09         | 0.56                | 0.4368        | 0.78     |         |
| industrial added value                            |              |                     |               |          |         |
| The reuse rate of water in factory district       | 0.09         | 60                  | 33            | 0.55     | 0.807   |
| Solid waste discharged per 10,000 yuan worth of    | 0.05         | 0.12                | 0.0744        | 0.62     |         |
| industrial added value                            |              |                     |               |          |         |
| The implementation of industrial policies         | 0.04         | 1                   | 0.7           | 0.7      |         |
| Environmental emergency response plan              | 0.05         | 1                   | 0.9           | 0.9      |         |
| Water-saving facilities                           | 0.05         | 1                   | 0.8           | 0.8      |         |
| Requirement for electroplating production line     | 0.08         | 1                   | 0.8           | 0.8      |         |
| Hazardous waste treatment                         | 0.04         | 1                   | 0.9           | 0.9      |         |
| The implementation of “Three Simultaneous”        | 0.06         | 1                   | 0.9           | 0.9      |         |
| Prevent measures for hazardous pollutants         | 0.05         | 1                   | 0.9           | 0.9      |         |

As is shown in Table 4, the current score for the cleaner production level of the factory is 0.807 points, which belongs to a relatively high level in domestic cleaner production. However, there is still room for improvement, such as: the fresh water consumption per 10,000 Yuan worth of industrial added value and the reuse rate of the entire plant's production water have low scores, and the water-saving facilities need to be improved.

4. The enterprise’s improved solutions for the cleaner production of and the secondary evaluation

4.1. Improved schemes for the cleaner production of the enterprise

According to the analysis results of 3.4, the following improved schemes are proposed to enhance the score of the enterprise’s cleaner production.

4.1.1. Automatic Control Scheme of Plating Cooling Water. Installing the pressure shutoff and water storage tank in the front of the cooling water pump. When the bath temperature rises, the solenoid valve opens, and the pressure in the front of the pressure switch will decrease, the water pump starts to work, and the cooling water begins to circulate. After the bath temperature drops to a normal level, the solenoid valve closes, the front pressure of the pressure switch returns to normal, the pump stops working, thus avoiding the long-term invalid work of the pump and save the energy as well as water.

4.1.2. Improvement of the Automatic Water Spraying System. In order to decrease the contaminants in electroplating wastewater, the automatic water spraying system needs to be improved as follows:

① The water pipe in the tank is changed into a titanium tube to improve the pressure resistance, aging resistance and corrosion resistance.

② Lengthen the flushing pipe, add 2 sets of nozzles and adjust the density of nozzle to assure that both the pull rod and the liquid blocking plate are in the spraying range. Besides, extend the liquid tray under the trolley to liquid blocking plate.
Increase the pressure pump to atomize the sprayed pure water, increase the spray range.

4.1.3. Ventilation installation plan for mechanical workshop. Because there are no ventilations around grinding machine and electric welder, the generated dust, water mist and fumes will affect the health of the employees. The water mist will also corrode equipment and workpieces.

In order to solve the problems mentioned above, install a cover board under the emery wheel and a draft tube above it. Besides, install a ventilation hood, ventilation ducts and fans at the electric welder machine. Thus, the dust, smoke, and water mist are generated in the coverage of ventilation hood and vent. Finally, install a control device to control the ventilations.

4.2. The Secondary Evaluation of the Enterprise’s Cleaner Production Level

After the implementation of all the improved solutions, the second appraisal is conducted to evaluate the cleaner production level of the factory. The results shows that the company’s quantitative indicators as well as resources and energy use indicators have all been improved, and the indicators for pollutant generated have all been decreased. And the result of the second appraisal is 0.868, which belongs to domestic advanced level.

5. Conclusions

The paper aims at evaluating the cleaner production level of a printing plate roller factory in the north. It constructs the evaluation index system and evaluation model to evaluate the cleaner production level of the enterprise, which is calculated to be 0.807, belonging to the domestic general level compared to the national standards. In response to the problems found in the evaluation process, this paper proposed three corresponding improvement schemes. After the implementation of all the schemes, the cleaner production level is improved to 0.868, which belongs to domestic advanced level. It proves that the improvement schemes effectively improves the cleaner production of the enterprise. At the same time, this paper can provide references for other enterprises in this field about cleaner production evaluation methods and the improvement methods, which can help to diagnose, control and eliminate emission sources.

However, it also has limitations. First, the research object of this paper is the printing plate roller factory in the north of China, so the evaluation index system may need a fine tuning if it is used in other factories. Second, though three improved solutions have been implemented, the cleaner production level still has much room to be improved.

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