Research on cleaner production potential of pipe pile industry based on material energy flow analysis

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Abstract: According to the characteristics of the PHC pipe pile production and taking the cleaner production audit of a PHC pipe pile company in Tianjin as an example, the cleaner production potential was analyzed in detail in the aspects of raw material and energy consumption, technical process and equipment, pollutant emission and so on. The material and energy balance analysis were carried out. This work provides reference for the development of cleaner production of PHC pipe pile industry.

1. Introduction
Pipe pile industry referred to prestressed concrete pipe pile belongs to the subdivision industry of concrete and cement products industry. The products are mainly used for the foundation construction of land construction projects such as high-rise buildings, expressways, elevated roads, large-scale power plants, ports, docks, large-span bridges and other large-scale water construction projects [1]. As the increase of the scale of infrastructure construction in China, the demand for pipe pile products is growing. However, a large amount of resources and energy are consumed in the production process, which brings about environmental pollution.

Cleaner production is a new concept. With the aim of "energy saving, consumption reduction, pollution reduction and efficiency increase", the whole production process is evaluated and analyzed through systematic and scientific procedures [2]. Thus, the consumption of resources and energy and the generation of pollutants from the source are reduced and eliminated during cleaner production process. From the perspective of development, energy saving and consumption reduction are the main development directions for pipe pile industry to reduce production cost. Cleaner production is an effective way for enterprises to achieve green and low-carbon development. At present, the cleaner production audit of pipe pile industry in China is still in its infancy stage. The practical case of cleaner production audit in the pipe pile industry is introduced in this paper, which provides guidance and reference for the implementation of cleaner production in the pipe pile industry in China.
2. General situation of pipe pile production enterprises
The main products produced by a pipe pile industry in Tianjin are high-strength prestressed concrete pipe piles with the outer diameter of 300 mm-1200 mm. Among them, the larger output is 400 mm and 1000 mm pipe piles. Construction facilities of the company mainly include pipe pile workshop, aggregate workshop, boiler workshop and so on. The company possesses 265 employees during the audit period. In order to achieve the cleaning of products, processes, equipment and site, the enterprise has conducted this round of cleaner production audit which can further reduce the consumption of raw materials, make rational use of energy, reduce the discharge of waste and pollutants, and recycle resources.

3. Raw and auxiliary materials and energy

3.1 Raw and auxiliary materials
Among the raw and auxiliary materials required for pipe pile production, steel bar, wire rod and strip steel are the raw materials for the production process of reinforcement skeleton. While cement, stone, sand and water reducing agent are the raw materials for the production process of concrete mixture. In order to produce products with high economic and technical indexes, all raw materials must meet the corresponding quality requirements.

3.2 Energy and water consumption
The main energy consumption of the pipe pile enterprise is electricity and coal, which are purchased from market. Electricity is used for the power supply to enterprises, while coal is used for coal-fired steam boiler to provide steam for pipe pile maintenance. The energy consumption structure of the pipe pile enterprise during the audit period (2020) is shown in Table 1 and Figure 1.

| Types of energy | Quantity | Equivalent quantity to standard coal (Equal value) /t | Equivalent quantity to standard coal (Equivalent value) /t |
|-----------------|----------|------------------------------------------------------|--------------------------------------------------------|
| Electricity /kW·h | 3368000 | 1360.7                                               | 413.9                                                  |
| Coal/t          | 6310     | 4933.8                                               | 4933.8                                                 |
| Water/m³        | 113917   | 27.67                                                | —                                                      |
| Total           | —        | 6322.17                                              | 5347.7                                                 |

Table 1 Energy consumption structure of the PHC pipe pile company during the audit period
As Table 1 shows, the equivalent quantity to standard coal of the comprehensive energy consumption is 5347.7 t during the cleaner production audit period. Among that, the electricity consumption is 3368000 kw·h and the coal consumption is 6310 t. It can be seen that the main energy consumption of enterprise is coal, accounting for 78% of the total energy consumption, followed by electricity which accounts for 21.5% of the total energy consumption (Figure 1). Steam maintenance is the main energy consumption process of pipe pile production. All using steam comes from coal-fired boiler, and electric energy is widely used in production. Therefore, the consumption of coal and electricity is the focus of energy saving in pipe pile enterprises.

The water used by the enterprise comes from the purchased tap water, and the consumed fresh water is mainly used for concrete mixing and boiler water. The loss mainly occurs in the steam curing process after the steam producing from boiler. After cooling, the remaining steam curing condensate water is discharged into desulfurization circulating water of boiler for secondary utilization. Other fresh water used in the production process is mainly including gravel cleaning water, mixer cleaning water and water for boiler dust removal process. Among them, water loss form the sand and stone cleaning process is large, mainly due to that the majority of cleaning water attached to the sand and gravel are carried away with the sand and stone. Other fresh water is mainly used for domestic bathing, toilet flushing, greening and dust reduction in the plant. The wastewater of the enterprise is treated by the sewage treatment station of the industrial park and discharged to the standard.

4. Current situation of contaminants production and discharge

4.1 Generation and treatment of water pollutants
Water pollutants in enterprises mainly include dust removal water of boiler, wastewater discharged from mixer and sand cleaning, condensate water of steam curing [3]. Among them, the dust removal water of boiler and wastewater discharged from mixer and sand cleaning are set with circulating pool for recycling and not discharged, while only a small amount of them are evaporated. The steam maintenance wastewater has high alkalinity [4]. After cooling, it is discharged into the desulfurization circulating water of boiler for comprehensive utilization.

4.2 Generation and treatment of air pollutants
The organized air emissions mainly include followings. 1) Coal fired boiler is the key energy consumption unit of pipe pile enterprises, so the air pollutants mainly come from coal. The flue dust and flue gas produced by coal-fired boiler are discharged by 45 m high exhaust funnel after being...
treated by water film dust removal and alkali wet flue gas desulfurization device. 2) For the dust generated in the concrete mixing plant, a combined pulse bag filter (dust removal efficiency of 99.5%) is installed on the top of each mixing building. After the dust generated in the batching bin and mixing room is collected and removed, the waste gas is discharged in the 20m high exhaust cylinder of the mixing plant. While, the unorganized air emissions mainly include dust from bulk storage, loading and unloading process.

4.3 Generation and treatment of solid waste
Among the solid wastes generated by enterprises, the slag generated by coal-fired boilers is sold for building materials, land filling and paving. The dust collected by the bag filter on the top of the mixing plant is reused for production. The sand and gravel generated from the precipitation of sand and gravel cleaning water, the steel waste generated from steel processing, and the cement slurry generated from the precipitation of steam curing condensate water are regularly recycled by the material recovery department with no secondary pollution [5, 6].

5. Material and energy balance analysis
Through the study of material and energy balance, the material and energy consumption of each production link of pipe pile enterprise are found out, and the potential of energy saving and emission reduction is further analyzed.

Figure 2 The thermal balance of steam curing process
Figure 3 The material balance of PHC pipe pile production in the company

As Figure 2 shows, the main heat loss includes processes of steam curing, autoclave curing opening and autoclave outer wall, which respectively account for 4%, 9% and 2% of the total heat produced by boiler steam. It can be seen that autoclave curing heat loss during the autoclave opening accounts for a large proportion. The heat loss during autoclave curing is mainly the steam lost and condensate generated during the autoclave opening process. The condensate generated in each kettle is about 10 t/D, and the temperature is about 90 ℃. While the heat loss of steam curing is mainly the condensate generated during steam curing process, with the amount of about 10t/D and the temperature of about 70 ~ 80 ℃. The condensation water generated by autoclave curing and steam curing should be effectively utilized to reduce heat loss.

Figure 3 shows that, almost all raw materials enter into the product, and the material loss only accounts for a small proportion. However, the sediment of sand and stone cleaning water accounts for 56.47% of the total loss, and the sediment of steam curing wastewater accounts for 38.5% of the total loss. Among them, the loss of precipitated sand and gravel accounts for the largest proportion, and the production rate of sand and stone cleaning needs to be further improved. Both of sand and gravel can be sold or recycled for comprehensive utilization [7].

6. Conclusions
Through analysis of energy consumption and sewage discharge of pipe pile industry, the energy and material balance studies are carried out to find out the problems existing in the energy conservation and emission reduction of enterprises. The loss of precipitated sand and gravel accounts for the largest proportion of material loss, and the production rate of sand and stone cleaning should be further improved. The condensed water produced by autoclave curing and steam curing is directly discharged into the circulating water for desulfurization of boiler after sedimentation, which should be effectively utilized to reduce the heat loss.

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