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Accounting Method and Application of thermal power generation's water footprint

WANG Zhao[1*], CHEN Qingwen[1], He Junfei[1], XIE Zeqiong[1], HUANG Jiayu[1], XIAO Zhenqian[1], ZHAO Ming[2], FENG Shaoshan[2]

[1]Guangzhou Institute of Energy Testing , Guangzhou 511447 , China

[2]Guangzhou Zhujiang Electric Power Co.LTD , Guangzhou 511458 , China

Corresponding author e-mail: 821427889@qq.com

Abstract. Thermal power generation has ranked the first in water consumption of industry in our country, at the same time our country is one of the poorest countries in water resource, it is necessary to take some measures to reduce water resource consumption and containment discharge specifically by accounting thermal power generation's footprint. This article analyses the research status on thermal power generation from domestic and oversea, and finds that the results of research are limited and a major part of scholars are focusing on one specific process only. Therefore this article based on the theory of water footprint has confirmed the boundary of thermal power generation's water footprint, established the accounting model of thermal power generation's water footprint, calculated the input of energy,the treatment of raw material, the water consumption used in diluting waste water and direct water intake respectively, and took a coal-fired power plant whose installed capacity is 300MW for example,and accounted its water footprint roundly. In the end, guided by the core of water saving in thermal power plant which lies in water saving and the reduce of drainage, this article comes forward some suggestion about water saving measures in thermal power plant, and provides reference for making some specific adjustment and improvement for thermal power plant and takes measures to reduce the consumption of water resource and the amount of contaminant.

1. Introduction

Water resource is an important resource which human being lives on, and the process of industrialization in human society aggravates the load of water resource environment. China is facing a serious situation of water resource, and the 13th five-year plan requires that the numerical control on the total amount and strength of water resource and so on. The researches of Liang Feifei et al[1]. indicate that thermal generation occupies the dominate state in power industry stably, and thermal power generation plant which ranks the first in the water consumption of industry needs to consume a large amount of water[2]. At the same time ,there are some relative foreign reports which indicate that thermal generation plants in America also account for 40% [3]of water intake quality.

In order to promote the sustainable development of society, after ecology footprint and carbon footprint, scientific community comes forward water footprint, a multi-dimensional index. The earnest concept of water consumption was given by Hoekstra[4] at 2002, which can clearly clarify how much fresh water used and clear water taken to dilute sewage in complete product life cycle. Water footprint which consists of green water print, blue water print and gray water footprint has been applied widely in water footprint of research area, water footprint of product and water footprint of consumption and so on. In thermal power generation area, the number of researches on the thermal power generation's water footprint from domestic and overseas are limited, especially in domestic. This is because the research on thermal power generation's water footprint is complicated, and affected by a lot of factors,such as the location of generation,water resource, season and population, and relative research institution are limited which accounts for difficulty in collecting data[3]. Nevertheless in relative research on thermal power generation's water footprint from domestic and overseas, a major part of scholars has put the emphasis of analysis on water circulation system, and not accounted strictly according to the concept of water footprint. Anna Delgado Martin et al. [3]came forward the analysis model of thermal generation's water footprint, I=A（HR-B)+C, in which I represents for the total water demand of thermal power plant, HR represents for the calorific value of thermal power plant, B represents for the total output of heat, HR and B are mainly related to the way of combustion and fuel used by the thermal power plant, and (HR-B) is the waste heat which needs cooling in thermal power plant; A represents the types of cooling system(constant current circulation system, 2 times circulation system and air cooling system); C represents for the need of other water consumption in thermal power plant(in which desulfurization system is the most effective on it). The scholars including Babkir Ali [5]and G.Kablouti [6]et al. were supported to and validated the opinion of Anna Delgado Martin, and drew the conclusion in specific example analysis: the way of thermal power generation which consumes the least amount of water is combusting traditional gas, the combination of gas-steam combination circulation and air cooling system; nevertheless the way consumes the largest amount of water is combusting shale gas, steam circulation and constant current circulation cooling system[7]. Mesfin M. Mekonnen et al. [8]came forward the calculation formula of calculating the total consumption of power generation's water footprint : $WF_{e,total} = \sum_{s}(E \times EM[s] \times WF_e[s])$. In this calculation, WFe,total represents for the total consumption of water; E represents for the amount of power generation; EM[s] represents for the percentage of a kind of fuel which accounts for a combination of fuel; WFe[s] represents for the consumption of water footprint for unit power generation which is the total amount of consumption in the three stages of supply chain (the supply of fuel, the build of thermal power plant and the process of thermal power plant). Shao Weiwei et al.[9] researched and compared each process's water footprint, and selected the most effective thermal power generation system in reducing the amount of water consumption by classifying the water use in whole process of thermal power generation.

It can be seen that there has not been a scholar accounting the amount of water use in thermal power generation plant strictly according ti the concept of thermal power plant from domestic and oversea, but only focusing on analysis on one or several thermal power generation's processes of water footprint, and they cannot conduct an accurate accounting or make measures specifically to reduce the consumption of water resource and the output of contamination. Therefore we have to build a relatively complete accounting model of thermal power generation's water footprint.

2.The accounting boundary of thermal power generation's water footprint

The system boundary of thermal power generation water footprint assessment is shown as figure1 ,whose research range includes the exploitation of raw material (steel bar, concrete and so on), the water consumption of smelting and transportation process, the input of energy,the treatment of raw material, the water consumption used in diluting waste water and direct water intake in operation process of thermal power plant, and the water consumption in the removal of thermal power plant after it is retired and waste water output in the whole process. While the accounting of industry water footprint only considers the accounting of operation water footprint, does not consider construction and scrap water footprint.

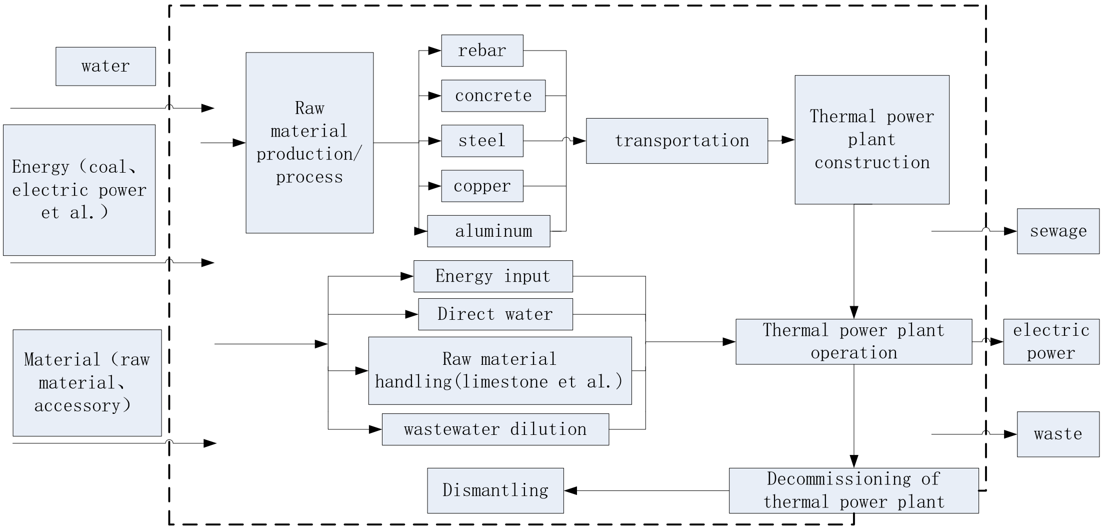

Figure 1. The system boundary of thermal power generation water footprint assessment

3.Accounting method

3.1 Energy and material water footprint

In thermal power generation, water footprint is equal to the product of its consumption and corresponding coefficient. Water footprint coefficient is in analogy with the concept of greenhouse gas emission factor,namely unit source/the value of material's product water footprint, which can be calculated according to formula(1):

$$L = L_{blue} + L_{gray} + L_{virtual} \quad (1)$$

In formula(1): L-sorce/material water footprint coefficient; Lblue-blue water footprint coefficient; Lgray-gray water footprint coefficient; Lvirtual-virtual water footprint coefficient.

The calculation formula of blue water footprint coefficient, gray water footprint coefficient and virtual water footprint coefficient are shown as formula (2), (3), (4), respectively:

$$L_{blue} = \frac{\sum (V_d - V_r)}{Q} \quad (2)$$

In formula (2): Vd-the amount of water intake inside the system boundary (volume); Vr-the amount of backwater use inside the system boundary (volume); Q source/material's activity intensity (quality or volume or kilometre or kwh).

$$L_{gray} = \frac{V_{effl} \times (C_{effl} - C_{nat}) / (C_{effl} - C_{nat})}{Q} \quad (3)$$

In formula (3): Veffl-the amount of waste water output inside the system boundary (volume); Ceffl-the concentration of waste water inside the system boundary (quality/volume); Cmax-the environmental water standard concentration of received water, that is the maximum acceptable concentration (quality/volume).

$$L_{virtual} = \frac{\sum_{i=1}^{n} M_i L_i}{Q} \quad (4)$$

Calculating resource's and material's water footprint coefficient needs two types of basic data, one is the input and output data of industry, and the other the system data of each major water area's environmental carrying capacity from domestic.It is difficult to gain these data, so we usually quote the data given by relative document directly. Common energy water footprint efficient of industrial production given by document[10,11] is shown as table1.

Table1. Common energy water footprint coefficient of industrial production

the name of the energy	unit	water footprint coefficient
Coal(raw coal)	m^3/t	7.01
Standard coal	m^3/t	9.81
Gas	m^3/t	9.25
Power(thermal power)	m^3/kWh	10.1510^{-3}
Steam	m^3/t	2.80
Vehicle-use unleaded gasonline	m^3/t	7.77
Light diesel oil	m^3/t	7.77
Coke	m^3/t	22.11

3.2 The operation water footprint of generation process

Besides of fuel, water is the most important material during generation process, which is both working fluid and vector, when it enters system and passes by a set of process it will lo a part of water in the end, and be discharged from system. Water as working fluid absorbs the heat released by fuel combustion and become steam with the capacity of making power. In addition, water is indispensable in other system in thermal power: the cooling water use of each auxiliary driving device, washing water use, greening water use in industry area, domestic water and so on. Water use units of thermal power plant is divided into circulation water system, chemistry water system(boiler feed water), industry water system,potable and fire fighting water system and so on[12]. This part can be calculated by statistical calculation of unit power generation and water intake quantity.

3.3 Thermal generation's gray water footprint

Thermal's gray water footprint means the water pollution degree index related ti this process, waste water discharged from thermal power generation contains containment including. Its definition is shown as the first sector of this article. The method of gray water footprint accounting: Firstly it needs to gain the standard concentration discharged from thermal power generation(Cnat, mg/L) and the natural background concentration(Cnat,mg/L), and then uses discharge capacity(L,t/s) divided by differential concentration which can gain gray water footprint. It's shown as formula(5):

$$L_{gray} = \frac{L}{c_{\max} - c_{nat}} \quad \text{(volume/time)} \qquad (5)$$

4.The appliance of thermal power generation's accounting method

The accounting of industry water footprint usually only considers the accounting of operation water footprint, according to the system boundary of thermal power generation water footprint assessment confirmed in section1, we only need to calculate the input of energy, the treatment of raw material ,the water consumption used in diluting waste water and direct water intake in operation process of thermal power plant.Taking a coal-fired power plant whose installed capacity is 300MW for example, according to the research made by writer before, unit's standard coal consumption is 0.34395kg/kwh, the amount of limestone per kwh is 0.01753kg/kwh. The water footprint coefficient of standard coal given by table 2 is 0.00981m3/kwh, the limestone water footprint coefficient is0.0531m3/kg[13]. According to investigation, a 300MW coal-fired power plant's water intake per power generation is 2.7610-4m3/kwh, discharge waste water per power generation is 1.4410-4m3/kwh, the mass concentration of COD and

BOD is 405mg/m3 and 121.5mg/m3[14]. Each responding pollution concentration in local surface water environmental concentration standard is 15 mg/m3 and 3mg/m3, the water consumption used in diluting waste water can be calculated according to formula (5). Then this thermal power runs some water footprint accounting results are shown as table 2.

Table 2. a 300MW coal-fired power plant runs some water footprint accounting results

	energy (coal) input	raw material handling (limestone)	direct water	dilute waste water
Water consumption （m^3/kwh）	3.3710-3	9.3110-4	2.7610-4	4.5310-4

5.Conclusion

(1)Thermal power generation's water footprint research can provide accurate information for thermal power plant to use water resource reasonably, regard the whole power generation process as investigation subject to calculate consumption quantity and pollution quantity in each stage in supply chain, and guide power generation. While at present, the theory of water footprint is still in exploration and development stage, so it need negotiation and completion no matter in theory or practical appliance.

(2)The accounting of industry water footprint usually only considers the accounting of operation water footprint, water footprint accounting in the operation process of thermal power generation includes the input of energy, the treatment of raw material, the water consumption used in diluting waste water and direct water intake.

(3)In thermal power generation, water footprint which is produced by energy and material is equal to the product of its consumption and corresponding coefficient. It is difficult to gain water footprint coefficient, so we usually quote the data given by relative document directly.

(4)Water system of thermal power plant's power operation system is divided into circulation water system,chemistry water system(boiler feed water), industry water system, potable and fire fighting water system and so on.

(5)The method of gray water footprint accounting: Firstly it needs to gain the standard concentration discharged from thermal power generation(Cnat, mg/L) and the natural background concentration(Cnat,mg/L), and then uses discharge capacity(L,t/s) divided by differential concentration which can gain gray water footprint

(6)Thermal power generation plant's principle of saving water is reducing fresh water use quantity, conducting waste water treatment, and improving the repeated utilization of water. Thermal power generation should choose suitable water saving measures and develop new water saving technology whose appliance is suitable to its own situation according to its own situation, and achieve water saving. The key of future investigation lies on making more complete and particular thermal power generation's water footprint assessment, index, and standard, accounting thermal power plant's water more accurately, and improving the appliance value of water footprint.

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