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Research Article

Calculation Model and Case Study of Water-Saving Quantity in Typical Industrial Enterprises

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Water-saving quantity is an important index to measure the effect of water saving. Scientific calculation of water-saving quantity is a basic content of water saving work, and is also an important means to carry out water saving evaluation and guide industrial enterprises to use water reasonably. This paper puts forward that the connotation of water saving is the improvement of water efficiency. Based on this, the calculation model of water saving in typical industrial enterprises is constructed. The water-saving quantity of textile enterprises and beverage production enterprises before and after water-saving technological transformation is calculated, which provides a reference for the calculation of water saving in typical industrial enterprises.

1. Introduction

More people and less water, uneven spatial and temporal distribution, and mismatch with the layout of productivity are the basic national conditions and water conditions in China. Water shortage, serious water pollution, water ecological deterioration, and other problems have become the main bottleneck that restricts the sustainable development of China's economy and society. In 2020, China's industrial water consumption of 103.04 billion m^3, accounting for about 17.7% of the total water consumption, including electricity, iron and steel, petrochemicals, textiles, light industry, and other high water consumption industries accounted for more than 60% of the total industrial water withdrawal. In recent years, in order to implement the "water conservation priority" water management ideas, to protect the implementation of national water conservation action, China's water conservation work has achieved significant results, industrial water conservation policy system and standard system is increasingly perfect, industrial water conservation technology transformation and innovation efforts continue to enhance, industrial water conservation publicity and pilot demonstration work is steadily advancing.

The scientific quantitative measurement of water saving effectiveness is an important basic work for the construction of water-saving society and an important technical tool for water saving evaluation and assessment work. At present, many domestic scholars have studied the calculation methods of water saving in agriculture, industry, public life, and other fields, considering different aspects such as water withdrawal, reuse of water, and water consumption. In the field of agriculture, water savings in irrigation areas are often measured by the evaporation estimation method, the diversion ratio method, or the water balance model method of irrigation areas. Yang et al. [1] used the ratio estimation method to calculate the water savings of water-saving irrigation projects in the main stream of the Heihe River. Yang [2] studied the calculation of water savings in irrigation areas with different water saving measures such as border field renovation, canal irrigation to sprinkler irrigation, canal irrigation to drip irrigation, planting structure adjustment, and channel lining, respectively. Shen [3] proposed the concept of real water saving. Wang [4] proposed that the water saving of water-saving irrigation measures includes the saving of reusable water and the saving of nonreusable water, and only the saved nonreusable water can be called the real water saving, and proposed the calculation method of real water saving. Shi et al. [5] calculated the real water saving of Youlian irrigation area in the middle reaches of the Heihe River, which consisted of three parts: direct water saving, indirect water saving, and assaulted diving evaporation, respectively. In the industrial field, the water saving of new water withdrawal is measured by calculating the improved reuse rate or reclaimed water reuse rate. Zeng et al. [6] proposed two methods for calculating water savings in oil and gas field enterprises: the unit consumption method and the comparison method. Lv et al. [7] proposed the "balance method" of water saving calculation based on the material balance theory, taking into account the characteristics of oilfield water use. Lv et al. [8] also researched the method of calculating water saving in long-distance oil and gas pipelines. However, they all focused on the water saving calculation of oil and gas field enterprises, and did not propose a water saving calculation method that is applicable to typical industrial enterprises.

In terms of national standards, GB/T 34148-2017 "Guidelines for calculating project water savings" proposes a basic method for calculating water savings in water-saving technology renovation projects [9], including the model method and the direct comparison method, but the standard only proposes the concept of water savings calculation without a specific calculation model, and the scope of application is water-saving renovation projects. GB/T 39186-2020 "Calculation method of water saving for projects in iron and steel industry" proposes the calculation method of water saving for water saving projects in iron and steel industry, which is not applicable to other industrial industries [10]. As for industry standards, SY/T 6838-2011 "Calculation method of energy and water saving for oil and gas field enterprises" proposes the calculation method of energy and water saving for oil and gas field enterprises [11], which is also not applicable to other industrial industries.

The international research on energy saving calculation is relatively mature, and the water saving mainly refers to the calculation method of energy saving. The EU countries use the cumulative energy savings calculation method, also known as the CUSUM method [12], which is relatively complex, but relatively accurate [13]. The International Protocol for Measurement and Verification of Energy Efficiency (IPMVP) gives four general methods for energy savings verification calculation based on this method, i.e., determining energy savings by measuring key parameters in the field, determining energy savings by measuring all parameters affecting energy consumption in the field, and determining energy savings by measuring energy consumption in the field. Determine the energy savings by measuring the energy-consuming facility as a whole or sub-consuming facilities, and determine the energy consumption by simulating the energy-consuming facility as a whole or sub-consuming facilities through computer software [14]. Therefore, there is a lack of international research on methods specifically for calculating water savings, especially for industrial enterprises.

To sum up, there is no unified scientific method specifically for water saving calculation of typical industrial enterprises at home and abroad. In practice, we generally take the water withdrawal data of two adjacent years and calculate the water saving by subtracting them, thus ignoring the impact of product output changes on enterprise water consumption; or simply add up the theoretical estimated water saving of various water saving measures to obtain the water saving, which ignores the operation of water saving facilities and the actual water saving effect. Therefore, it is important to carry out research on the calculation methods and model construction of water saving in typical industrial enterprises to scientifically evaluate the actual water saving effect of industrial enterprises, guide them to use water reasonably and carry out water-saving evaluation.

2. The Connotation and Calculation Model of Water-Saving Quantity

On the concept of water saving, scholars at home and abroad have proposed the concept of water withdrawal, water consumption saving, and "real water saving" considering water consumption [3–5]. Western developed countries have accumulated rich experience in water resources management, and have formed a relatively complete management system for the management and evaluation of water conservation. They believe that defining water conservation as the reduction of net water consumption can benefit the water supply of other uses; if water conservation is defined as the reduction of water diversion, it may harm the water supply of other uses. The indicator of true water savings is the amount of nonrecoverable water loss reduced by the water savings [15].

In practice, there are often two misunderstandings about water savings: one is that a reduction in water withdrawal is equivalent to water savings, and the other is that an increase in water withdrawal must not be water savings. Both of these understandings are not scientific and objective, because water use efficiency is not improved only due to significant reductions in output and services and less water, this situation is not water savings. Likewise, the fact that water savings are generated does not necessarily mean that water withdrawals are reduced, as they may increase if water use efficiency is improved while output is significantly increased. Water savings connotes an increase in water use efficiency, which is the combined result of effective use of management and technical measures.

Therefore, water savings connotes the amount of water used to provide the same quantity and quality of product or service for less water due to water use efficiency improvements. Under stable operating conditions, for a typical industrial enterprise, the indicator of water use efficiency is the amount of water withdrawn per unit of product, i.e., the amount of water taken to produce a unit of product within a certain measurement time. Through the effective implementation of management and technical measures, the amount of water taken per unit of product is reduced, water use efficiency is improved, and the resulting reduction in water used to provide the same quantity and quality of products is the water saving of a typical industrial enterprise.

Based on the connotation of water savings, the "water withdrawal-product yield" model is established. Calibrated water withdrawals and water savings are measured based on the water withdrawal and product yield statistics for the base and statistical reporting period. When industrial enterprises produce multiple products, they should be counted and calculated separately. The parameters of the model include project water savings (ΔW_s), base period water withdrawal (W_b), statistical reporting period water withdrawal (W_r), and calibration water withdrawal (W_a), which are related as shown in Figure 1. W_b and W_r are derived by measuring water withdrawal from industrial enterprises, and W_a is derived by establishing a quantitative relationship between water withdrawal and product output and calibrating product output for the statistical reporting period, reflecting the water withdrawal of a typical industrial enterprise without improving water conservation management and adopting water conservation measures.

The basic formula for calculating water savings in industrial enterprises is shown in

$$\Delta W_s = W_a - W_r. \tag{1}$$

In the Equation,

ΔW_s—Water-saving quantity for industrial enterprises, in cubic meters (m^3),

W_a—Calibrated water withdrawal, in cubic meters (m^3),

W_r—Statistical reporting period water withdrawal, in cubic meters (m^3).

The calibrated water withdrawal is obtained by calibrating the water withdrawal per unit of product in the base period with the actual output in the statistical reporting period, and the calculation formula is given in

$$W_a = \sum_{i=1}^{n} V_{bui} \times Q_{ri}. \tag{2}$$

In the equation,

V_{bui}—Water withdrawal per unit of product for the base period of product *i*, in cubic meters per unit of product.

Q_{ri}—The production of the product *i* in statistical reporting period.

The formula for calculating unit product water intake in base period is shown in

$$V_{bui} = \frac{W_{bi}}{Q_{bi}}. \tag{3}$$

In the equation,

W_{bi}—The total amount of water withdrawn from various water sources during the production of the product *i* for the base period, in cubic meters (m^3),

Q_{bi}—The base period production of the product *i*.

Statistical reporting period water withdrawal can be measured by the enterprise level meters, or can be calculated from the statistical reporting period of the unit product water withdrawal and product output, and the calculation formula is given in

$$W_r = \sum_{i=1}^{n} V_{rui} \times Q_{ri}. \tag{4}$$

In the equation,

V_{rui}—The *i*-th product statistics of the reporting period, the unit of product water withdrawal in cubic meters per unit of product.

The formula for calculating water withdrawal per unit of product for the statistical reporting period is shown in

$$V_{rui} = \frac{W_{ri}}{Q_{ri}}. \tag{5}$$

In the equation,

W_{ri}—The total amount of water withdrawn during the statistical reporting period from various water sources in the production process of the *i*-th product, in cubic meters (m^3).

The calculation of water savings for a typical industrial enterprise can also be expressed by

$$\Delta W_s = \sum_{i=1}^{n} V_{bui} \times Q_{ri} - W_r = \sum_{i=1}^{n} (V_{bui} - V_{rui}) \times Q_{ri}. \tag{6}$$

From the water saving calculation model constructed above for a typical industrial enterprise, it can be seen that the key variable affecting its water saving is the decrease in water withdrawal per unit of product, that is, the improvement of its water use efficiency. If there is no improvement in water use efficiency, there will be no water savings.

3. Calculation Case of Water-Saving Quantity

This paper further analyzes and illustrates the use of the water saving calculation model through the following two specific case studies.

3.1. Case 1

3.1.1. Basic Information. A textile enterprise mainly produces two types of products: cotton color woven fabric and knitted fabric. 2020, the enterprise carried out water-saving technical transformation, including the world's most advanced fully automated dyeing cylinders in the printing and dyeing workshop; the introduction of continuous knitted fabric washing machines in the knitted fabric washing process; the recycling of cooling water in the finishing workshop for vacuum dewatering machines, ginning machines, and other machines, and the recycling of steam condensate in the dryer barrels. In order to make the base period and the statistical reporting period comparable, the base period and the statistical reporting period are set as January to December 2019 and January to December 2021, respectively.

The output of the products produced by the textile company was measured and counted in the base period and the statistical reporting period, respectively. The water withdrawal data for the base and statistical reporting periods can be obtained by measuring and metering means, and the relevant data are shown in Table 1.

3.1.2. Unit Product Water Intake. Unit product water extraction according to Equation (3) and Equation (5) for calculation, because the enterprise produces two types of products, it is calculated separately, the results are shown in Table 2.

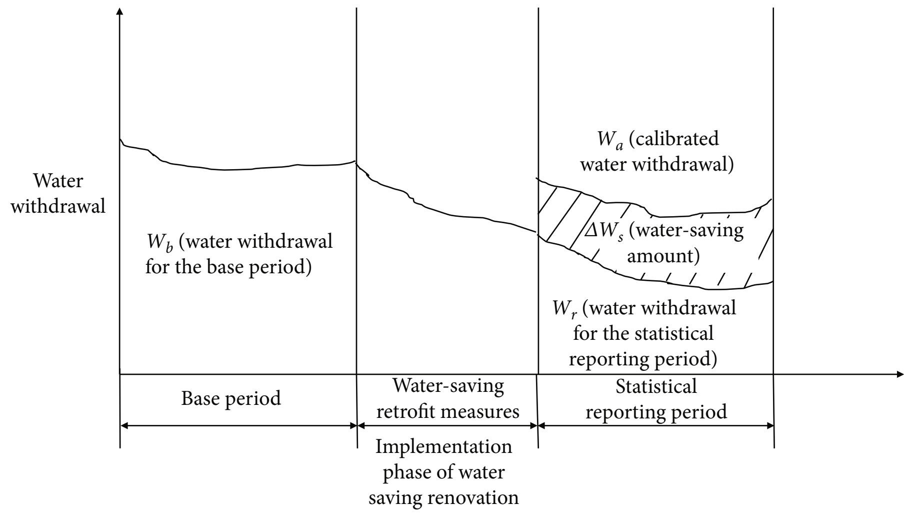

Figure 1: Schematic diagram of relevant parameters.

Table 1: Production and water withdrawal data before and after water-saving transformation of a textile enterprise.

Time	Data statistics period	Product name	Output	Water intake	
Base period	January to December 2019	Cotton cloth	11939 million meters	167.15 million m^3	356.42 million m^3
		Knitted fabric	19314 tons	189.27 million m^3	
Statistical reporting period	January to December 2021	Cotton cloth	104.52 million meters	114.97 million m^3	284.64 million m^3
		Knitted fabric	18852 tons	169.67 million m^3	

Table 2: Unit product water intake before and after water-saving transformation of a textile enterprise.

Time	Data statistics period	Product name	Unit product water intake
Base period	January to December 2019	Cotton cloth	$1.4\,m^3/100\,m$
		Knitted fabric	$98\,m^3/t$
Statistical reporting period	January to December 2021	Cotton cloth	$1.1\,m^3/100\,m$
		Knitted fabric	$90\,m^3/t$

Table 3: Comparison of water withdrawal reduction and water-saving quantity.

Water-saving quantity	Water withdrawal reduction	Decrease of product output	
		Cotton cloth	Knitted fabric
$464400\,m^3$	$717800\,m^3$	14870000 m	462 tons

3.1.3. Water-Saving Quantity. According to Equation (6), the water saving of this textile company is calculated.

$$\Delta W_s = (1.4 \times 1045200 + 98 \times 18852) - 2846400 = 464400\,m^3, \quad (7)$$

Or

$$\Delta W_s = (1.4\text{-}1.1) \times 1045200 + (98\text{-}90) \times 18852 = 464400\,m^3. \quad (8)$$

By comparing the water withdrawal per unit product in 2019 and 2021, the water use efficiency of cotton and knitted fabric increased by 21.4% and 8.2%, respectively. And the resulting water saving achieved was $464400\,m^3$, while the water withdrawal decreased by $717800\,m^3$, which is because the water use efficiency of the enterprise was improved in 2021 while the product output was also reduced, so the water saving was smaller than the reduction of water withdrawal. See Table 3 for details.

3.2. Case 2

3.2.1. Basic Information. A beverage manufacturer mainly produces carbonated beverages. In 2020, the company carried out water conservation improvement projects such as water reuse at the bottom of carbon filter tanks, water reuse

Table 4: Production and water withdrawal data before and after water-saving transformation of a beverage manufacturer.

Time	Data statistics period	Product name	Output	Water intake
Base period	January to December 2019	Carbonated beverage	124070 tons	169800 m^3
Statistical reporting period	January to December 2021	Carbonated beverage	160275 tons	187500 m^3

Table 5: Unit product water intake before and after water-saving transformation of a beverage manufacturer.

Time	Data statistics period	Product name	Unit product water intake
Base period	January to December 2019	Carbonated beverage	1.37 m^3/t
Statistical reporting period	January to December 2021	Carbonated beverage	1.17 m^3/t

Table 6: Comparison of water withdrawal reduction and water-saving quantity.

Water-saving quantity	Water withdrawal reduction	Increase of product output
32000 m^3	-17700 m^3	36205 tons

for bottle backwashing in the filling plant, and strengthened its water conservation management efforts. In order to make the base period and the statistical reporting period comparable, the base period and the statistical reporting period are set as January to December 2019 and January to December 2021, respectively.

The production volume of products produced by this beverage producer was measured and counted in the base period and statistical reporting period, respectively. The water withdrawal data for the base and statistical reporting periods can be obtained by measuring and metering means, and the relevant data are shown in Table 4.

3.2.2. Unit Product Water Intake. Unit product water withdrawal is calculated according to Equation (3) and Equation (5), and the results are shown in Table 5.

3.2.3. Water-Saving Quantity. According to Equation (6), the water saving of this beverage producer is calculated.

$$\Delta W_s = 1.37 \times 160275 - 187500 = 32000, \tag{9}$$

Or

$$\Delta W_s = (1.37\text{-}1.17) \times 160275 = 32000\,\mathrm{m}^3. \tag{10}$$

By comparing the water withdrawal per unit of product in 2019 and 2021, the enterprise's water use efficiency improved by 14.6%, and the resulting water savings achieved were 32000 m^3, while the water withdrawal increased by 17700 m^3. Since the enterprise's product output increased by 36205 tons in 2021, the water use efficiency increased, but the enterprise's water withdrawal increased, and the relevant data are shown in Table 6.

4. Conclusion

Through the calculation and analysis of models and cases, we can see that for a typical industrial enterprise, water savings can be generated only if the water withdrawal per unit of product decreases, i.e., the water use efficiency increases. If product output increases, the water savings will be less than the reduction in water withdrawal. If product output decreases, the water savings will be greater than the reduction in water withdrawal. Only if the product output remains the same will the water savings be equal to the reduction in water withdrawal.

The water saving calculation model for a typical industrial enterprise constructed in this paper reflects the essential factors affecting water saving with the key variable of water withdrawal per unit of product, considering both the change of product output and the actual water saving effect, and can scientifically elaborate and explain the connotation of water saving. It is of great significance to support the calculation of water saving and the evaluation of water saving effect of typical industrial enterprises, and will effectively promote the improvement of water measurement statistics, water saving management, and technical level of industrial enterprises.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

It is declared by the authors that this article is free of conflict of interest.

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