Research on the Thermal Properties of Urban Native Sewage Based on Regression Model

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Abstract. At this stage, due to the lack of research on the basic thermophysical parameters of urban primary sewage, the change of thermophysical state of sewage cannot be well grasped, resulting in a low utilization rate of low-grade thermal energy of primary sewage. In this paper, a regression model is established based on the existing data to analyze the changes of basic thermophysical parameters such as density, thermal conductivity, constant pressure specific heat and other basic thermal properties of residential and industrial sewage at different sewage temperatures. Through model analysis, it is found that the density of residential sewage is significantly lower than that of industry. The sewage density of both types of sewage reached a maximum of about 10°C at a sewage temperature, and then showed a decreasing trend again. The thermal conductivity of residential sewage is lower than that of industrial sewage, and the thermal conductivity of sewage gradually increases with the increase of sewage temperature; From the analysis of constant pressure specific heat of sewage, the specific heat of residential sewage is greater than that of industrial type, and the specific heat of sewage decreases with the increase of temperature, and the change range is small.

Keywords: Sewage thermal physical properties, Regression model, Clean energy

1. Introduction

With the acceleration of socialist modernization and the advancement of industrialization, China's energy demand has also further increased. The heating energy consumption of northern cities in China is large, about 213 million TCE in 2019, accounting for 20% of the total building energy consumption in the country; From 2001 to 2019, the building heating area of northern cities in China increased from 5 billion square meters to 15.2 billion square meters [1]. Establishing a reasonable energy structure and improving energy utilization efficiency are the proper meaning of achieving new progress in the construction of ecological civilization.

Heat pump technology is a technology that uses the reverse Carnot cycle to convert low-grade heat energy in air, water, soil and other substances into high-grade heat energy to realize building heating in winter and cooling in summer, which has significant energy-saving effects and greatly reduces environmental pollution compared with the direct combustion of fossil fuels [2]. As one of the effective energy-saving methods to reduce building energy consumption, sewage source heat pump has very good environmental benefits. At present, there are few research problems on the thermal and physical parameters of primary sewage in the practical

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engineering application of urban sewage source heat pump system, including the relationship between parameters such as density, thermal conductivity and constant pressure specific heat of primary sewage and sewage temperature [4]. In this paper, MATLAB software is used according to the existing data, and Stata software further analyzes the mathematical relationship between relevant parameters, and establishes the regression model of sewage density on sewage temperature, sewage thermal conductivity on sewage temperature, and regression model of sewage constant pressure specific heat and sewage temperature from the perspective of urban residential and industrial sewage. Through these studies, it provides a reference calculation model for the popularization and application of sewage source heat pump and the study of the thermal physical properties of native sewage in cities.

2. Materials and Methods

The data used in this paper are all cross-sectional data, so it is suitable to use regression model to establish a model for the change of different sewage thermophysical parameters at different sewage temperatures, and to achieve the prediction effect by analyzing the regression model, which provides a reference mathematical model for the study of urban native sewage thermophysical properties.

A) Regression model:

x is the explanatory variable and y is the explanatory variable.

The task of regression analysis is to try to explain the formation mechanism of y by studying the correlation between x and y, and then achieve the purpose of predicting y through x [3].

B) Residuals:

Suppose x is the independent variable and y is the dependent variable, and the following linear relationship is satisfied

$$y_i = \beta_0 + \beta_1 x_i + u_i \tag{1}$$

and is the regression coefficient, and u is the unobservable perturbation term that meets certain conditions

Let the predicted value

$$\widehat{y}_i = \widehat{\beta}_0 + \widehat{\beta}_1 x_i \tag{2}$$

$$\widehat{\beta}_0\ \widehat{\beta}_1 = \underset{\beta_o, \beta_1}{arg\min} \left(\sum_{i=1}^{n} \left(y_i - \widehat{y}_i \right)^2 \right) = \underset{\beta_0, \beta_1}{arg\min} \left(\sum_{i-1}^{n} \left(y_i - \widehat{\beta}_0 - \widehat{\beta}_1 x_i \right)^2 \right) \tag{3}$$

We call x residuals[5-7]

C) Endogeneity:

Suppose the model is $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + u$

u is an unobservable perturbation term that meets certain conditions.

If the error term u and all independent variables are not correlated, the regression model is said to be exogenous, and if it is related, there is endogenous, and endogenous will lead to inaccurate estimation of regression coefficients, unbiased and consistent [8]

3. Results & Discussion

3.1 Model analysis of effluent density and effluent temperature

The density of sewage at different sewage temperatures is shown in Table 1.

Table 1: Density of sewage at different sewage temperatures

Temperature t (℃)	**Residential** ρ_1 (kg/m^3)	**Industrial** ρ_2 (kg/m^3)
5	995.3	1004.1
10	997.0	1004.8
15	996.0	1004.0
20	995.2	1002.0
25	994.1	1001.1
30	993.2	1000.8

The above is the existing data of the density of native sewage in a city at different temperatures, based on this data, we perform regression analysis in Stata software, find a model with large goodness-of-fit, small error squared sum by constantly changing the model power series and correlation coefficients, and finally verify by graphing to obtain the following regression model:

3.1.1 Regression model of residential sewage density

$$\rho(t) = 0.00096t^3 - 0.06t^2 + 0.98t + 991.9 \tag{4}$$

The R-square of this wastewater density fitting formula is 0.9628, and the sum of squared errors SSE is 0.3378.

3.1.2 Industrial wastewater density regression model

$$\rho(t) = 0.0013t^3 - 0.071t^2 + 0.99t + 1001 \tag{5}$$

The R-square of this wastewater density fitting formula is 0.9908, and the sum of squared errors is 0.1343.

In this regression model, the power series of the independent variables is no longer square, but because the linear function considered in this article refers to linearity to the parameters, that is, linear to the parameters, the model here is still a linear regression model. Although the power series of the dependent variable in the model reaches the third power, the correlation coefficient is small, and the density of sewage fluctuates less with temperature.

On the basis of the above model, we use MATLAB to map and visualize the results. The thermal conductivity of sewage as a function of temperature is shown in Figure 1.

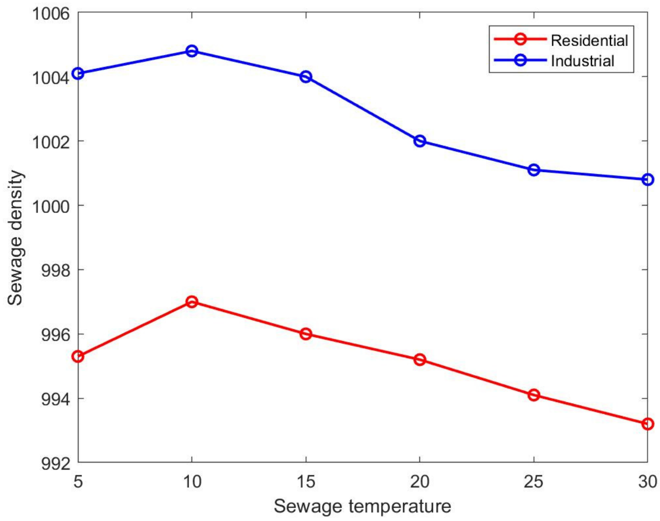

Figure 1. Curve of wastewater density as a function of temperature

3.2 Model analysis of sewage thermal conductivity and sewage temperature

The thermal conductivity of sewage at different sewage temperatures is shown in Table 2.

Table 2 Thermal conductivity of sewage at different sewage temperatures

Temperature t (℃)	**Residential** λ_1 ($W/(m \cdot ℃)$)	**Industrial** λ_2 ($W/(m \cdot ℃)$)
5	0.582	0.587
10	0.590	0.597
15	0.596	0.606
20	0.602	0.615
25	0.612	0.623
30	0.617	0.630

Based on the existing experimental data, the relationship between the thermal conductivity of sewage corresponding to different types of buildings was fitted:

3.2.1 Regression model of thermal conductivity of residential sewage

$$\lambda(t) = 0.0014t + 0.575 \quad (6)$$

The thermal conductivity of this wastewater fits the R-square of 0.9932.

3.2.2 Regression model of thermal conductivity of industrial sewage

$$\lambda(t) = 0.0017t + 0.5797 \tag{7}$$

The thermal conductivity of this wastewater fits the R-square of 0.9932. The thermal conductivity of sewage varies with temperature as shown in Figure 2.

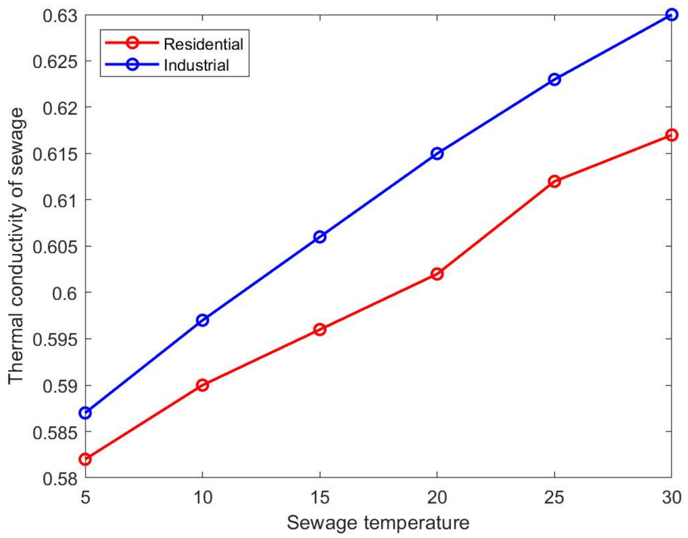

Figure 2: Thermal conductivity of wastewater as a function of temperature

It can be found from the figure that the slope of the thermal conductivity curve of residential sewage has a sudden change at 20~25 °C, while the slope of the industrial thermal conductivity curve is relatively stable.

3.3 Model analysis of constant pressure specific heat of sewage and sewage temperature

The specific heat at constant pressure of sewage at different sewage temperatures is shown in Table 3.

Table 3 Constant pressure specific heat of sewage at different sewage temperatures

Temperature t (℃)	**Residential** c_{p1} ($J/(kg \cdot ℃)$)	**Industrial** c_{p2} ($J/(kg \cdot ℃)$)
5	4171.0	3902.5
10	4161.2	3894.0
15	4155.3	3888.5
20	4150.2	3883.4
25	4147.6	3878.3
30	4146.0	3873.5

Based on data fitting, the relationship between the specific heat of sewage corresponding to different types of buildings is obtained:

3.3.1 Constant pressure specific thermal regression model of residential sewage

$$c_p(t) = 0.0387t^2 - 2.332t + 4181 \tag{8}$$

The R-square of the constant pressure specific heat fitting formula for wastewater is 0.921 and the SSE is 0.8363.

3.3.2 Constant pressure specific thermal regression model for industrial sewage

$$c_p(t) = 0.014t^2 - 1.629t + 3910 \tag{9}$$

The R-square of this constant pressure specific heat fitting formula for wastewater is 0.997 and the SSE is 1.51.

The change of specific heat of sewage constant pressure with temperature is shown in Figure 3.

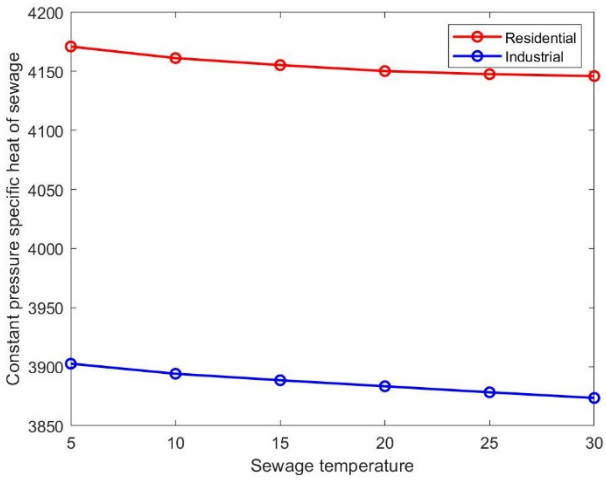

Figure 3: Curve of specific heat of wastewater with temperature

4. Conclusions

A) From the aspect of sewage density, it can be found that the density of residential sewage is significantly lower than that of industry. The sewage density of both types of sewage reached a maximum of about 10 °C at a sewage temperature, and then showed a decreasing trend again, among which the decline of industrial sewage fluctuated greatly, which may be related to the increase in temperature and the reaction of chemicals contained therein.

B) From the aspect of sewage thermal conductivity analysis, residential sewage thermal conductivity is lower than industrial, sewage thermal conductivity with the increase of sewage temperature and gradually increase, through consulting the data we found that below 15 °C two types of sewage thermal conductivity value difference is small, with the sewage temperature continues to increase, the difference between the thermal conductivity of the two types of sewage becomes larger [1]. At the same time, it can be found that the increase in the thermal conductivity of residential sewage becomes larger after the sewage temperature reaches 20 °C, and returns to the normal level after 25 °C, while the increase in the thermal conductivity of industrial sewage changes more steadily with the increase of sewage temperature and fluctuates less.

C) From the analysis of constant pressure specific heat of sewage, the specific heat of residential sewage is greater than that of industrial sewage, and the specific heat of constant pressure of both types of sewage decreases with the increase of temperature, and the change range is small. The difference in thermal conductivity between the two types of sewage remains about 270, which is less affected by the change of sewage temperature.

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