Change of Water Fluid Temperature at Its Treatment in Open Sites

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Abstract. The main aim of the work is to study the natural and climatic factors influence on the degree of change in waste fluid temperature in open facilities, depending on the design features of the main facilities (primary sumps, aeration tanks and secondary sumps), indicators for the sewage treatment, as well as a year seasons. It should be noted that today waste fluid temperature influence on the processes of sedimentation and biological treatment has been studied and mathematically described quite well. The high convergence of theoretical result, obtained using these mathematical models in the design with production data, has been repeatedly verified and proved. The statistical data collection on STF operating of Novosibirsk and Iskitim (Novosibirsk region) on the changes in waste fluid temperature at different stages of its purification was carried out for a long time, covering all seasons of the year. Mathematical processing of statistical data made it possible to obtain multivariate regression models that could be used to predict the actual temperature of waste fluid, depending on the operating conditions of wastewater treatment complex.

1. Introduction

The long-term practice of open sewage treatment facilities operating (STF) of the Russian Federation with its various climatic conditions has shown that, the indicators of treated wastewater begin to gradually deteriorate and reach peak values in the coldest winter period, even with good technical condition and proper operation of a facility. As a detailed examination result of a sufficiently large number of STF’s technical conditions, as well as laboratory production control data analysis, we could consider that this was primarily due to a decrease in waste fluid temperature, not only STF entering, but also during its cleaning in open sites (primary sedimentation tanks, aeration tanks and secondary sedimentation tanks). The influence of climatic conditions affects primarily in areas with sharply continental climate in the Russian Federation (Western and Eastern Siberia). The dry, hot climate, observed in the Krasnodar Territory and the Republic of Crimea, also has an adverse effect on STF operation. Unfortunately, despite the importance of the climate impact on the open sewage treatment plants’ efficiency, this issue still remains completely unstudied. An attempt to fill an existing gap is made in our work. Today, one of the most pressing problems is the slow deterioration in the wastewater treatment quality during the cold season, which is associated with a decrease in the efficiency of wastewater treatment plants for all functioning STF. The main indicators’ values (BOD and suspended solids) grow and reach maximum values in winter, exceeding the maximum permissible concentrations (MPC) established for discharge into a reservoir. What is the reason?
The fact was the main structures of wastewater treatment complexes in the USSR, and later in the Russian Federation were designed for the average annual temperature of the wastewater supplied to the treatment without taking into account its changes during purification in open facilities until 2016. And as you know, primary sumps, aeration tanks and secondary sumps have huge areas of waste fluid contact with outside air.

Today, the question of choosing the wastewater estimated temperature has been radically revised, according to SN 32.13330.2012 “Sewerage. External networks and constructions” It is recommended that the minimum and maximum calculated temperatures’ values of wastewater be taken as the average for two weeks with the corresponding extreme values for three years of observation. By the way, there are no comments on changes in waste fluid temperature during its treatment in open facilities in this document. And this can only be explained by the lack of the issue study.

The goal of this work consists precisely in studying the natural and climatic factors influence on the degree of change in wastewater temperature in open structures, depending on the design features of primary settlers, aeration tanks and secondary settlers, the wastewater treatment quality, as well as the seasons [1-4]. It should be noted that today the waste fluid temperature influence on the processes of sedimentation and biochemical oxidation of organic substances has been studied and mathematically described quite well [5,6]. Repeatedly verified and proven high convergence of theoretical calculation results with production data.

The research objectives included the statistical data collection on changes in waste fluid temperature in the main structures (primary and secondary sedimentation tanks, as well as aeration tanks). The research objects were two STF functioning sites of Novosibirsk and Iskitim (Novosibirsk region) [7,8]. The choice of these objects was due to three reasons. Firstly, they are located in almost the same climatic zones, characterized by cold winters and hot summers. Secondly, they have different capacities, and therefore different heat capacities: Novosibirsk STF is designed to receive effluents in the amount of 840 thousand m³/day, and 50 thousand m³/day in Iskitim. Thirdly, both objects have different design of primary sedimentation tanks, aeration tanks and secondary sedimentation tanks, which means that they are protected from cooling differently. The primary and secondary vertical settling STF tanks in Iskitim have a depth of about 9 m. Therefore, they have a smaller contact surface of waste fluid with the outside air, ceteris paribus.

Statistical data was collected over a long time period, covering repeatedly all four seasons of the year. The waste fluid temperature was measured in primary sumps, aeration tanks and secondary sumps during the day at the inlet and outlet; sludge mixture temperature, returned from the secondary settling tanks to aeration tanks, was also measured. Unfortunately, measurements were made only in the daytime and this is due to the work safety. At the same time, wind speed was recorded at a height of 2 m from water surface, humidity and atmospheric pressure. In parallel, the efficiency of the primary sedimentation tanks, aeration tanks and secondary sedimentation tanks was monitored by organoleptic, hydrobiological, physical and chemical indicators.

Organoleptic indicators (color, smell and transparency) were checked during the research period [9]. Clarity is not only a simple analysis, but also a highly reliable indicator. It can be confidently stated that wastewater has undergone deep biological treatment with a value of more than 20 sm. We can note pH and suspended solids, which are easy to determine and give an idea of the wastewater quality of the simple and affordable analyzes that reflect the wastewater physical state. All chemical analyzes (COD, nitrogen group, phosphorus group, sulfur group, chloride) are also easy to determine if LCK tests and a spectrophotometer are used [10]. The biological indicator of BOD5 was not determined due to its implementation duration, as well as its "moodiness". The data reliability, obtained for this indicator, is influenced by many factors that are extremely difficult to predict at the time of the sample preparation for analysis. Hydrobiological analysis of activated sludge is the most reliable and easily mastered with microorganisms’ atlas of activated sludge and with the corresponding comments.

Heat-mass transfer processes, occurring in open structures between waste fluid and environment, were theoretically studied in the process of collecting statistical data [11]. Waste fluid begins to lose
heat and can be cool slightly in open sites even when waste fluid temperature is equal to the outside temperature. Moreover, the degree of cooling is as higher, as wind speed is and the lower of outside air humidity. In winter, the cooling degree increases due to an increase in the temperature difference between waste fluid and environment. Fog that occurs on frosty days over open sites somewhat reduces the degree of waste fluid cooling. In spring, waste fluid temperature can decrease to a greater extent, in comparison with the winter period during snow melt and massive influx of melt water into the sewer network. The same phenomenon can be observed in the autumn period when cold storm water enters. Significant cooling of drains can be observed at STF of large megacities where snow melting plants operate. Heavy snowfalls and snowstorms with the large snow masses can also reduce waste fluid temperature in open sites, but not significantly. Although during the blizzard, the degree of cooling increases, but not because of snow enters into open structures, but due to intense evaporation and convective heat transfer.

2. Materials and Methods

As it was already noted, the collection of statistical data on changes in wastewater temperature in open facilities was carried out at STF operating sites of Novosibirsk and Iskitim (Novosibirsk Region). The outdoor temperature drops to -37°C on the coldest five-day period, and on the coldest days to -41°C. In summer, temperature rises to +40 °C during the hottest five-day period, and to +45 °C on the hottest day in the areas where these two sites are located.

The measuring points of waste fluid temperature in the sites remained unchanged throughout the long-term period of information data collection. So, the first measurements were made at the input and output of the primary sump. The second measurements were carried out in an aeration tank: the temperature of activated sludge returned from the secondary sump and the mixture of wastewater with circulating activated sludge, as well as the sludge mixture at the aeration tank outlet, were measured. The third measurement included biologically treated waste fluid temperature at the outlet of the secondary sump. The temperature of the sludge mixture, entering the secondary sump, was taken equal to the temperature of the sludge mixture leaving the aeration tank. The assumption was made that the decrease in the sludge mixture temperature in a closed pipeline in the section from the aeration tank to the secondary sump was so small that it could be taken equal to zero.

Climatic factors were fixed, namely atmospheric pressure, wind speed, relative humidity and outdoor temperature [12,13]. High-precision measuring instruments were used to carry out a series of measurements, namely: TESTO 905-T1 was a thermometer for measuring of waste fluid temperature, TESTO 410-2 was an anemometer for measuring wind speed, relative humidity and outdoor temperature, TESTO 511 was a manometer for recording atmospheric pressure. The journal noted the date and time of measurements, which were subsequently used in the processing of experimental data.

The TESTO 905-T1 sensor was immersed into wastewater and held there until the temperature was displayed. Climatic parameters were recorded before measuring waste fluid temperature. Measurements were taken every 2 hours.

2.1. Mathematical processing of the research results

Cluster analysis procedure was previously applied, due to the fact that the measurements were carried out at different times of the year in order to achieve sample uniformity for constructing regression models. Then, hypotheses of difference significance in the average values of the measured parameters in the obtained homogeneous subsamples, using Student t-test, were tested, and only after that regression dependencies were built [14]. Statistical sample studies were carried out using SPSS 17.0 statistical package.

The study of the experiment’s sample homogeneity of measurements was carried out by including the cluster analysis procedure [15] “Two Step Cluster Analysis”. Two-stage cluster analysis procedure was designed to identify natural groupings (or clusters) in a data set that would otherwise not be obvious. The algorithm, used in this procedure, had several desirable features that distinguished it from traditional clustering methods:
- processing of categorical (qualitative) and continuous variables [16];
- automatic selection of the clusters’ number;
- scalability. Two Step algorithms allow you to analyze large data files by building a tree of cluster functions.

The data were seasonality meters (winter and spring). Quantitative meters were: wastewater temperature, outdoor air, wind speed, relative humidity and atmospheric pressure.

3. Results
The experimental data processing for Novosibirsk STF with a large number of measurements (120 measurements), carried out only for the period of spring and winter, are highlighted in the article. A similar processing was performed for the STF statistical data in Iskitim, 252 measurements were made on this object.

First of all, a cluster analysis divided the total sample into two clusters: cluster 1 was in spring and cluster 2 was in winter. The cluster partition analysis indicated a significant decrease in the variation of the main measures in cluster 1 (average square deviation of the outdoor temperature 2.4), compared to the total sample, which could not be considered to cluster 2 (average square deviation of the outdoor temperature 10.2), where the variation of the main parameters were comparable with their variation in the total sample (average square deviation of the outdoor temperature 10.3). This suggested that the sample winter period under consideration was characterized by significant fluctuations in the outside air.

We compared the sample averages in the resulting clusters using the Student t-test, since the sample clustering was performed to obtain homogeneous subsets described by approximately normal distributions in order to correctly construct linear multivariate regression models.

The results of testing hypotheses about the parameters’ average values equality in the obtained clusters indicated with a high degree of reliability that the hypothesis about the average values equality of the climatic and technological factors (wastewater temperature of STF) in the clusters was not confirmed. Because, climatic factors differently affected on one of the main STF indicators in the winter and spring periods - waste fluid temperature.

Models were built for each selected cluster of observations, as well as for the entire set of measurement data (general sample).

An important step in constructing the multiple regression equation was the selection and subsequent inclusion of its factor attributes. The problem of selecting factor attributes for constructing relationship models can be solved on the basis of intuitive-logical or multidimensional mathematical-statistical analysis methods.

The most acceptable way to select factor signs is stepwise regression (stepwise regression analysis). The essence of the step-by-step regression method is to implement algorithms for sequentially including, excluding, or including-excluding factors in the regression equation, followed by checking their statistical significance. The problem of selecting factor attributes for constructing relationship models can be solved on the basis of intuitive-logical or multidimensional mathematical-statistical analysis methods. The model construction in 5 steps is shown in table 1.

The resulting model is quite high quality. It explains more than 75% of variations in wastewater temperature due to the inclusion of climatic factors. In this case, the standard error of the model does not exceed 0.66 degrees 0C. As a result, it can reliably predict temperature fluctuations with fluctuations in the climatic characteristics values.
| Step | Model Parameters | Model coefficients (not standardized) | Standardized coefficients | Student t-test | Relevance |
|------|------------------|----------------------------------------|---------------------------|---------------|-----------|
|      |                  | B          | Standard error | Beta         |          |
| 1    | Free member      | 18.016     | 0.118         | 152.070      | 0.000     |
|      | Outside temperature, degrees | 0.098       | 0.008         | 12.976       | 0.000     |
| 2    | Free member      | 15.460     | 0.488         | 31.651       | 0.000     |
|      | Outside temperature, degrees | 0.096       | 0.007         | 14.004       | 0.000     |
|      | Relative humidity% | 0.036       | 0.007         | 5.362        | 0.000     |
| 3    | Free member      | 59.127     | 10.826        | 5.462        | 0.000     |
|      | Outside temperature, degrees | 0.065       | 0.010         | 6.557        | 0.000     |
|      | Relative humidity% | 0.028       | 0.007         | 4.283        | 0.000     |
|      | Atmospheric pressure, mmHg | -0.057      | 0.014         | -4.037       | 0.000     |
| 4    | Free member      | 61.545     | 10.057        | 6.119        | 0.000     |
|      | Outside temperature, degrees | 0.075       | 0.009         | 7.917        | 0.000     |
|      | Relative humidity% | 0.021       | 0.006         | 3.337        | 0.001     |
|      | Atmospheric pressure, mmHg | -0.058      | 0.013         | -4.474       | 0.000     |
|      | Wind speed, m / s | -0.203      | 0.046         | -4.450       | 0.000     |
| 5    | Free member      | -6.988     | 33.240        | -210         | 0.834     |
|      | Outside temperature, degrees | 0.088       | 0.011         | 7.900        | 0.000     |
|      | Relative humidity% | 0.014       | 0.007         | 2.021        | 0.046     |
|      | Atmospheric pressure, mmHg | -0.079      | 0.016         | -4.940       | 0.000     |
|      | Wind speed, m / s | -0.155      | 0.050         | -3.096       | 0.002     |
|      | Date of measurement | 0.002       | 0.001         | 2.160        | 0.033     |

The most influential factor, as it can be considered by the standardized (dimensionless) model parameters, is the outdoor temperature, which positively affects fluid temperature. When this parameter changes by 1 degree, waste fluid temperature changes by almost 0.1 degrees.

The resulting regression equation is as follows:

\[ y = -6.988 + 0.088T_{\text{outside air}} + 0.014\varphi - 0.079P_{\text{atmosphere pressure}} - 0.155v + 0.02D \]

Where \( T_{\text{outside air}} \) is outdoor temperature, °C;
\( P_{\text{atmosphere pressure}} \) is outdoor atmospheric pressure, mmHg;
\( \varphi \) – relative humidity, %;
\( v \) – wind speed, m / s;
\( D \) – measurement date.

This regression model is presented using non-standardized coefficients, and it has different dimensions. It is necessary to consider standardized coefficients (Beta) to assess precisely the influence of any climatic factor, which is given dimensionless.

A scatter plot was also obtained for the total sample (Figure 1)
Figure 1. Scatter plot for a general sample model with a dependent variable (waste fluid temperature).

Cluster 2 (winter) was analyzed according to the same principle as the general sample. The accuracy characteristics’ analysis of this cluster and their comparison with the accuracy characteristics of a model, constructed from a common sample of observations, showed a significant increase in the quality indicators of the winter cluster model. The determination coefficient increased by almost 10%, showing the explanatory power of the model, but the accuracy model characteristics importantly increased. The standard error of the model decreased by 0.08 degrees \(^\circ\)C.

In this case, the model contains 3 parameters, but not 5, as it was in the case with the general sample.

The resulting regression equation is as follows:

\[ y = 16.762 + 0.151 T_{\text{outside air}} + 0.022 \varphi + 0.436v \]

where \( T_{\text{outside air}} \) is outdoor temperature, \(^\circ\)C;
\( \varphi \) – relative humidity, %;
\( v \) – wind speed, m / s.

Outside temperature strongly affects waste fluid temperature, as it was before in the general sample. But in this case, wind speed is the most influential parameter.

The scattering diagram for cluster 2 is shown in Figure 2.

Figure 2. Scatter plot for a winter season model with a dependent variable (waste fluid temperature).
We give an example of one more model constructed for cluster 1 of the spring months’ observations. A feature of the spring model is a significantly low coefficient of determination in contrast to previously constructed models. This can be explained by the classification, which led to the fact that the variation of the main indicators in this cluster was very low. It also practically led to the fact that the average value of wastewater temperature varied in a very narrow range, and modeling of its changes in this cluster did not lead to significant changes in the parameters of prediction accuracy. The spring months model is one-factor and the change in waste fluid temperature is determined only by changes in atmospheric pressure.

The resulting regression equation looks like:

\[ y = 149.262 - 0.173P_{\text{Atmosphere pressure}} \]

where \( P_{\text{Atmosphere pressure}} \) is atmospheric pressure of external air, mm Hg.

Moreover, waste fluid temperature increases with a decrease in atmospheric pressure, as it can be judged by the obtained model.

A diagram of the regression model of this cluster is shown in Figure 3.

![Figure 3](image)

**Figure 3.** Scattering diagram for the spring season model with a dependent variable (waste fluid temperature).

4. Discussion

The studies’ results showed that wastewater temperature in open sites is affected by: wastewater temperature supplied for treatment, outside temperature, 2 m height - speed wind from water surface, atmospheric pressure and relative humidity. Mathematical processing of experimental data revealed the degree of natural and climatic factors influence on wastewater cooling in open sites.

Cooling in its structures, wastewater is hardly freed from suspended particles in the primary settling tanks, as its viscosity increases. Biochemical oxidation processes of soluble and insoluble organic substances are inhibited in biological treatment plants. The processes of activated sludge particles deposition are worsened in secondary sedimentation tanks, as well as in primary ones, due to an increase in water density.

Excessive cooling of wastewater in biological treatment plants, designed for the nitrification and denitrification process, in some cases can lead to a natural restructuring of the biological treatment unit's operating mode into a regular aeration tank, which reduces only BOD and suspended solids.

The problem can be partially solved for functioning sewage treatment plants at the stage of reconstruction of the wastewater treatment complex by introducing a more advanced of a sites construction or changing the technology of wastewater treatment.

For newly designed complexes, the volumes of open sites must be determined taking into account the
degree of waste fluid cooling during its treatment, depending on the climatic factors of the construction site. The research results were used to create a computer model that allows analyzing and predicting the quality of the treated wastewater using the following initial data: temperature entering the wastewater receiving tank, BOD, suspended solids, nitrogen, pH, as well as the natural and climatic parameters of a site’s design area.

5. Conclusion
The operational data surveying of functioning wastewater treatment complexes showed that one of the urgent problems existing at these facilities is a slow decrease in their work efficiency with the onset of the cold season and the worst indicators achievement of treated wastewater in the coldest five days.

1. It was established that in the world practice of wastewater treatment this issue was completely ignored, and it still remained unexplored as a result of a literature review, which was carried out to determine the influence of natural and climatic factors on the temperature change of wastewater during its purification in open sites.
2. The purpose of this research is to study the influence of climatic conditions on the degree of change in waste fluid during its treatment in open facilities (primary sumps, aeration tanks and secondary sumps), where it is located for a long time.
3. The essence of the research was to collect statistical data on wastewater temperature at the inlet and outlet of primary sumps, aeration tanks and secondary sumps in different seasons of the year. The place of research was two sites of Novosibirsk and Iskitim operating STF, differing in productivity and design of open ones.
4. A cluster analysis was obtained during the collection of statistical data, and it was found that different periods of the year had different effects on waste fluid temperature. The greatest influence on the cooling degree of wastewater in winter, exerted by the outdoor temperature and wind speed, and humidity and atmospheric pressure, were less affected.
5. The obtained multivariate regression models are supposed to be used to create a computer model that will analyze and predict the efficiency of sewage treatment plants.

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