

Specialized Method of Calculating Heat Input from Wastewater in the Premises of the Sewage Pumping Stations

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Abstract. Modern sewage plant is a complex engineering structure with a different configuration of functional sectors (zones). The inlet sections to the pumps operate in a gravity flow mode, characterized by incomplete filling of the section with water, based on the requirements of non-absorption of ventilation safety for the resulting gas, mainly methane. As the liquid and gas have a higher temperature than the air temperature in the premises of the pumping stations. The problem of heat flow from the fluid have to be solved by a specially designed method that takes into account the separation of gas and liquid flows in pipes and rectangular channels by applying the theory of similarity, criteria equations and computational experiment. An important circumstance in the structure of the algorithm of the calculation is finding and using the concept of the wetted perimeter, as well as newly introduced in the article the concept of the average heat transfer coefficient with respect to the specific configuration of each element partially filled with liquid. Pumps and pipes after them as usual completely filled with water, but here in turn, we have to consider a special form of surfaces of equipment and fittings drainage systems.

1. Introduction

In this article, we present a model for determining the heat transfer from wastewater to the premises of sewage pumping stations (SPS). For figure .1 the conditions of non-blocking for gravity Sewerage networks are presented. In pressure networks, the filling (ratio h/d) will be equal to one, because it is believed that water fills the entire volume of the pipe

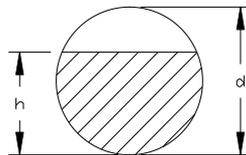


Figure 1. Diagram of a non-filled pipe.

The theoretical data for the calculation are obtained by the similarity method and the corresponding criteria [1,2] by the similarity numbers.



General cases of heat exchange during the flow of liquid in the channels were also reflected in the developments of other authors [3,4]. The main difference was that the heat transfer was taken as a constant throughout the entire length of the path. In the theory of similarity, the heat transfer characteristic is the average value on the considered part. It takes into account averagely as the unevenness of the flow in different areas, and the temperature change at individual points in the course of the fluid and the heat exchange potential. Besides, M. A. Razakov calculated the value of heat supply from various pipes and channels where waste water flows.

In Figure 2 and 3 has shown a typical sewage pumping station [5,6]. We are conventionally accepted to divide the heat transfer zones into the room, taking into account the configuration and degree of filling of the water channels, which corresponds to the specialization of the formulas for calculation. Authors characterize these zones: I – zone receiver with natural ventilation; II – zone camera with wastewater and rake bars; III – the suction area of the pump; IV – discharge area of the pump; V–zone of sending wastewater to treatment facilities. In zones I and II, the flow is divided into liquid and gas phases (the filling of pipes <1). The channel shape in the cross section is rectangular. In zones III, IV and V the flow is continuous and the filling of the pipes is 1, the shape of the pipes is round. The structure of pumping stations is shown in Figure.2 and 3.

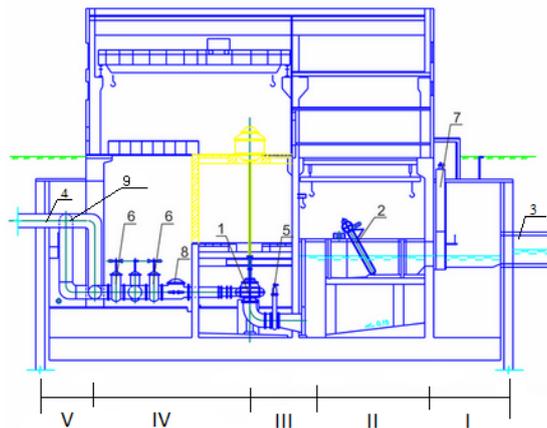


Figure 2. Principal type of sewage pumping station (section 1-1).

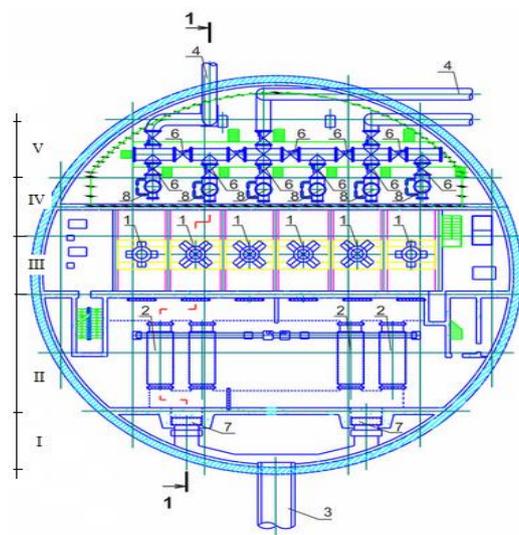


Figure 3. Principal view of the sewage pumping station (plan of the underground part)

1. Vertical sewage pump (III zone); 2. Grab screen (II) 3. The feed line (area III); 4. Discharge pipeline (IV zone); 5. Valve on the supply pipeline (III zone); 6. Valve on the discharge pipe (IV zone); 7. Shield gate with electrical drive (I zone); 8. Non-return valve (IV zone); 9 – discharge emerging from the SPS of the pipeline (V zone).

Since the main operating room of the pumping station is below ground level (machine room), the temperature changes slightly during each calculation period of the year (winter, summer). Therefore, conditionally accept in further reasoning and calculations carried out for the winter period that the air temperature in the room is constant. Transfer of heat from pipes in the thickness of the walls may be ignored. We also accept that the gas and the liquid phases in the pipe have the same speed.

2. Methods of calculating the thermal conditions

General view of the heat transfer equation through a cylindrical wall with the filling of the pipe for one phase.

$$Q_l = K_l \cdot F \cdot (t_i - t_o) = K_l \cdot \pi \cdot d_n \cdot l \cdot n \cdot (t_i - t_o), W \quad (1)$$

K_l - linear heat transfer characteristic, $W/m^2 \cdot ^\circ C$;

d_n - nominal diameter, m;

n - number of pipelines;

l - the length of the considered segment in the center of the axis of the pipeline, m;

t_i - temperature of waste water inside the pipeline [7 and SP 31.13330.2012];

t_o - outside temperature of the pipeline environment [8].

Linear heat transfer characteristic from one environment to another

$$K_l = \frac{1}{\sum R}, W / m^2 \cdot ^\circ C \quad (2)$$

$\sum R$ - the sum of thermal characteristics of heat transfer, $m^2 \cdot ^\circ C / W$.

Sum of heat transfer resistances

$$\sum R = R_i + R_p + R_o, m^2 \cdot ^\circ C / W; \quad (3)$$

R_i - thermal resistance of heat transfer from the internal environment to the pipe, $m^2 \cdot ^\circ C / W$.

R_p - thermal resistance to heat transfer of pipe thickness, $m^2 \cdot ^\circ C / W$.

R_o - thermal resistance to heat transfer from the pipe to the outer environment, $m^2 \cdot ^\circ C / W$.

Resistance to heat transfer from the internal environment to the pipe

$$R_i = \frac{1}{d_1 \cdot \pi \cdot \alpha_i}, m^2 \cdot ^\circ C / W; \quad (4)$$

d_1 - the inside diameter of the pipe, m;

α_i - heat transfer characteristic from the internal environment to the wall, $W / m^2 \cdot ^\circ C$.

Heat transfer resistance of pipe thickness

$$R_p = \frac{1}{2 \cdot \pi \cdot \lambda} \cdot \ln \frac{d_2}{d_1}, m^2 \cdot ^\circ C / W; \quad (5)$$

λ - characteristic of thermal conductivity of the pipe material, $W / m \cdot K$;

d_2 - pipe outside diameter, m.

The resistance to heat transfer from the pipe to the outer surface

$$R_o = \frac{1}{d_2 \cdot \pi \cdot \alpha_o}, m^{2o}C/W; \quad (6)$$

α_o - heat transfer characteristic from the pipe to the external environment, $W/m^{2o}C$.

Characteristic of convective heat transfer from the internal environment to the wall

$$\alpha_i = \frac{Nu \cdot \lambda}{d_n}, W/m^{2o}C; \quad (7)$$

Nu - Nusselt characteristic;

λ - thermal conductivity, $W/m \cdot K$.

General equation of the criterion equation of convective heat transfer

$$Nu = c \cdot Re^n \cdot Gr^b \cdot Pr^m \cdot \left(\frac{Pr}{Pr_{cm}}\right)^{0.25}; \quad (8)$$

c, n, b, m - experimental numerical parameters determined by experimentation;

Re - Reynolds number, determines the mode of fluid flow;

Gr - Grashof number;

Pr - the Prandtl number;

$\left(\frac{Pr}{Pr_{cm}}\right)^{0.25}$ - correction taking into account the direction of heat flow.

The Reynolds number determines the mode of fluid flow. The number Grashof is an extra factor. The nature of fluid motion (mode) can be laminar or turbulent, in this regard, the experimental numerical parameters in the criterion equation can be different.

$$Re = \frac{\omega \cdot d_n}{\nu}; \quad (9)$$

ω - flow rate of waste water in the pipeline, m^3/c ;

ν - characteristic of kinematic viscosity [9,10], m^2/c ;

$$Gr = \frac{g \cdot l^3 \cdot \beta \cdot \Delta T}{\nu^2}; \quad (10)$$

g - acceleration of gravity, m/c^2 ;

β - volumetric expansion characteristic, K^{-1} ;

ΔT - temperature difference between indoor and outdoor environments, oC ;

All areas of heat supply have a different mode of fluid flow. Characteristic of convective heat transfer from the pipe to the external environment depends by the orientation of the heated surface [11]:

The total heat transfer characteristic consists of the convective and radiant components

$$\alpha = \alpha_c + \alpha_r, W/m^{2o}C; \quad (11)$$

α_c и α_r - characteristics of radiant and convective heat transfer, $W/m^{2o}C$;

Special for zone 1. Features of heat exchange of liquid and gases phases with solid walls are determined by the intensity of heat flow into the air zone of the SPS and require to identify the numerical values of the heat transfer characteristics to take into account various thermal processes.

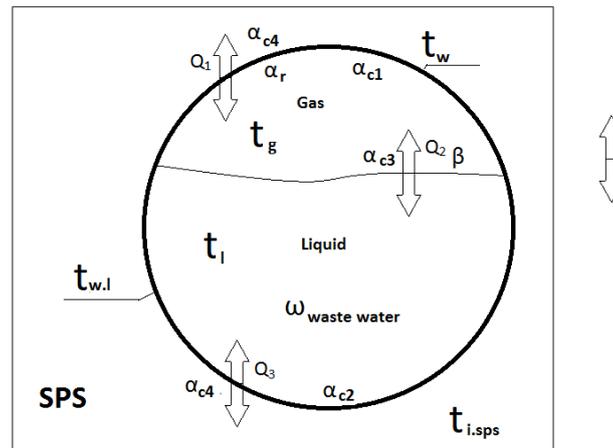


Figure 4. The circuitry of heat and mass exchange in the space of the zone with waste water in the sps, a round shape with liquid and gases phases is shown.

There is a gas phase in each zone where is heat exchange with the walls and heat transfer through the walls of structures.

The heat transfer Q_1 can be written as:

$$Q_1 = (\alpha_c + \alpha_r) \times (t_g - t_w) \times F_w, \text{ W} \quad (12)$$

$$Q_1 = \alpha_{k4} \times (t_{i.sps} - t_w) \times F_w, \text{ W} \quad (13)$$

F_w - the area of the wall which associated with heat transfer from the gas phase to the air in the sps m^2 ;

α_c - characteristic of convective heat exchange, $W / m^2 \cdot ^\circ C$;

α_r - characteristic of radiant heat exchange, $W / m^2 \cdot ^\circ C$;

t_g - temperature of the gas phase, $^\circ C$;

t_w - wall temperature, $^\circ C$;

$t_{i.sps}$ - air temperature in the sps, $^\circ C$.

The wall temperature in formulas 12 and 13 may differ in the calculation of the thermal conductivity process inside the wall.

In each zone there are two phases liquid and gas, between of them there is a heat and mass transfer by convective heat exchange (Q_2) and evaporation of the liquid phase and condensation of vapors during the transition to the liquid phase (W).

$$Q_2 = \alpha_{k3} \times (t_l - t_w) \times F_l, \text{ W} \quad (13)$$

$$W = \beta \times (c_l - c_g) \times F_l \quad (14)$$

F_l - the area of the interface between liquid and gas phases, m^2 ;

α_{k3} - characteristic of convective heat transfer, $W / m^2 \cdot ^\circ C$;

β - characteristic of moisture transfer, m/s ;

c_l - the concentration of streams in the liquid phase above the liquid surface, kg/m^3 ;

c_g - the concentration of streams in the liquid phase in the space occupied by the gas phase, kg / m^3 ;

t_l and t_w - temperatures of the gas and liquid phases, respectively in the zone of their contact, $^\circ C$.

In the liquid phase, there is also heat exchange with the surface of the walls of structures (Q_3).

$$Q_3 = \alpha_{k2} \times (t_l - t_{w.l}) \times F_{w.l}, \text{ W} \quad (15)$$

$$Q_3 = \alpha_{k4} \times (t_{w.l} - t_{i.sps}) \times F_{w.l}, \text{ W} \quad (16)$$

$F_{w.l}$ - surface area which washed by the liquid phase, m^2 ;

α_{k2} - characteristic of convective heat transfer between the liquid phase and the wall, $W / m^2 \cdot ^\circ C$;

α_{k4} - characteristic of convective heat transfer between the wall surface and the air of the sps, $W / m^2 \cdot ^\circ C$;

t_l - temperature of the liquid phase, $^\circ C$;

$t_{w.l}$ - the temperature of the wall washed by the liquid phase, $^\circ C$;

$t_{i.sps}$ - air temperature in the sps, $^\circ C$;

The total heat flux in each zone can be recorded as follows

$$Q = Q_1 + Q_2 + Q_3 \quad (17)$$

As an assumption, vaporization and condensation of streams of the liquid phase in the gas phase were not taken into account in this article.

3. Results of calculations

We present our results (Calculation of heat transfer to the sewage pumping station rooms from waste water) in Table 1.

The building of the sewage pumping station is located in the city of Zelenograd. We take the temperature of waste water because it is the average of the possible temperatures: 6 – 20 $^\circ C$ [12-15, according to table.34 SNiP 2.04.03 - 85].

Zone 1: Speed of wastewater flow in the pipe-0.5 m/s;

Nominal diameter of pipes-500 mm;

Number of pipes (n) - 2;

Length (l) - 6 m;

Zone 2: 0.5 m / s; 500 mm; 12 m;

Collector: 0.5 m / s; length of the plot (l) - 2 m;

Zone 3: 1.5 m / s; 300 mm; 5; 6 m;

Zone 4: 3,0 m/s; 300 mm; 5; 15 m;

Zone 5: 3,0 m/s; 300 mm; 5; 4 m;

Table 1. Calculations of heat transfer to the sewage pumping station rooms from waste water

<i>N_o of zone (Phase)*</i>	<i>ω_w m/s</i>	<i>L, m</i>	<i>Re 10^4</i>	<i>K $W/m^2 \cdot ^\circ C$</i>	<i>F, m^2</i>	<i>Q, W</i>
1(L)	0,5	6	23,4	6,8	18,8	640
2(L)	0,1	4	37,4	6,8	175,6	6085
2(G)	0,5	2	7,6	5,7	24	685
2(G)	0,1	4	3,0	3,5	332	5800
2(G)	0,5	6	22,7	4,7	12	280
3(L)	1,5	6	42,1	6,8	28,4	965
4,5(L)	3,0	19	84,10	6,8	89,5	3055

L – liquid phase of the waste water; G - gas phase waste water.

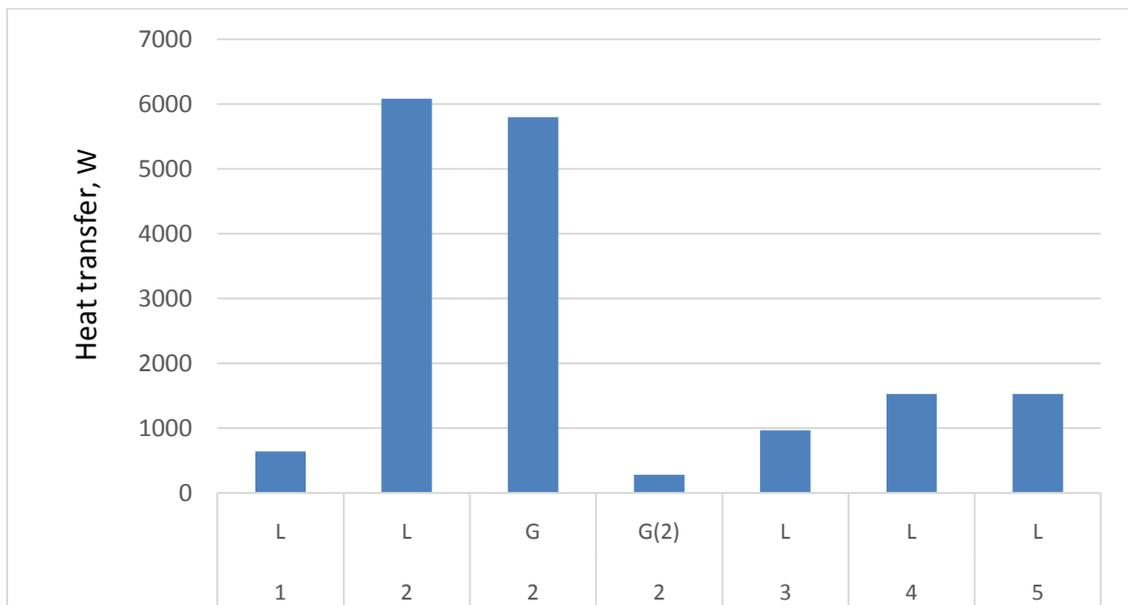


Figure 5. The Intensity of heat transfer from waste water (zones (1-5) to rooms)

4. Conclusion

Previously, such detailed methods for the analysis of thermal discharges from wastewater in the SPS were not used. The proposed method allows to study the processes of heat dissipation and heat losses in the air space of heated rooms in the SPS. It is a complex consideration of air and thermal regimes [16] in the SPS and the thermal regime of waste water that allows to obtain a picture of changes in the temperature regime in the SPS in any periods of the year. The analysis of the heat flux intensity from each zone allows to form an understanding of the processes that would allow to intensify the flow of heat energy to increase the reliability of the required thermal regime during periods of a sharp drop in the temperature of the outside air in the winter. The total heat transfer from wastewater in the design mode for the premises considered as an example of the SPS from all the considered zones is equal to 17500 W, which allows to obtain the required temperature of the internal environment.

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