Urban Pneumatic Transport Development Trends for Domestic Solid Waste Disposal

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Abstract. This article provides the results of the urban pneumatic transport development prospects for domestic solid waste (DSW) collection and transportation studies. Peculiarities have been considered, and the proposals have been given concerning the improvement of the pneumatic transport efficiency for the DSW disposal by using the suction-discharge unit. Method has been provided for calculation of the main structural and technological parameters of the suction-discharge unit for waste removal.

1. Introduction

DSW collection and transportation problem today is one of the most topical ecological problems that the modern cities face [1]. Ordinary collection and transportation of the DSW corresponds to anti-hygienic condition of the container sites, unpleasant work for staff engaged in waste collection, traffic jams, and air pollution caused by garbage trucks. Pneumatic transport that collects the waste using the air stream through the underground pipeline, in most cases, may eliminate these problems.

Despite the successful use of the pneumatic transport for the DSW disposal abroad [2], in Russian cities this method has not yet found use owing to a range of reasons analyzed in this paper.

In terms of action principle, the existing pneumatic transportation units may be divided in suction (vacuum) and discharge ones [3]. In suction units, the material to be transported enters the suction pipeline because of the vacuum in this pipeline created by the vacuum pipe, and the materials may be collected from multiple points simultaneously. Depending on the vacuum at the end point of the transportation system, the suction units may be divided into low residual pressure units (up to 0.01 MPa), medium (up to 0.03 MPa), and high (up to 0.09 MPa) residual pressure. Increase in residual pressure reduces the air flow density, reduces the air carrying capability, and increases the air flow rate. Relatively high DSW mass concentrations in the suction units may be achieved only in case of short transportation distance (up to 1.0 km). To transport the DSW within greater distance (up to 10 km), discharge units should be used [4]. In discharge-type units, the material is transported in the air flow by the boost pressure created by the compressor and dedicated air blowers. Discharge units may be classified by the pressure in the transportation grid starting point: low (up to 0.11 MPa), average (up to 0.2 MPa), and high (up to 0.9 MPa) pressure units. Discharge units are convenient when the material from one place should be transported to multiple receivers [5].

2. Results

According to the studies carried out at the Housing & Utility Department, NI MGSU [6], to improve the pneumatic transportation system efficiency for the DSW transportation, it is reasonable to use the
combined waste disposal system, where the suction and discharge systems are unified into a single pneumatic transportation unit (figure 1). In this case, the waste disposal technology will be implemented as follows.

![Figure 1. The combined waste disposal system](image)

Waste is collected in dedicated concentrator shafts 1 installed in the buildings in the garbage chutes lower part, in crawl space. Waste in residential and public buildings of the micro region get into the concentrator shafts through the standard waste doors 2, which limits the maximum size of the waste entering the system to 300-350 mm. 1-2 times a day, depending on the DSW accumulation rate in the shafts, the system is activated to serially transport the DSW from the concentrator shafts to the hub station 7. Concentrator shafts are connected to each other by pipelines forming the single pneumatic transport grid 3. Hub station, if possible, should be located in the center of the micro region served by the system, that is why the transportation pipelines grid has the radially branch structure. In each of the pipeline branches, i.e. in the most distant point from the hub station, there is an air induction valve 4. Typically, a branch connects not more than 25-30 shafts, which reduces the air entrainment through the DSW leaking input valves, since the non-operating branches of the system are sealed by the dedicated valves located at the points of connection with the transport pipeline. To transport the DSW after the air blow launching, the air induction and sealing valves 5 of the branch open. Herewith, an air flow is created in it, which flows through the pipeline 6 with speed 24-28 m/s, and ensures the DSW components movement. Command from the control panel opens the induction valve closest to the hub station. Own weight and static pressure differential cause the entire waste mass to be transferred from the concentrator shaft to the pipeline. Then, the induction valve closes.

After the first portion of the DSW enters the transportation pipeline upon the command from the control panel, the next induction valve opens - a new portion of the DSW enters, and so on. Opening of next valve occurs upon the recovery of the air flow parameters in the pipeline, i.e. after non-stationary processes end in it, after the grabbing the previous portion. When all concentrator shafts of the working branch are unloaded, air induction and sealing valves close upon the control panel command. After emptying of the concentrator shafts of all branches, the DSW go to the hub station 7, where after passing through the gateway 8 they get into the discharge pipeline. Air blower 9 in the intermediate point sucks air from pipeline 6 and discharges to pipeline 10 at the same time.

DSW that have entered the pipeline will be moved in the air flow by the boost pressure to the destination (incinerator or processing plant). Before the DSW will be sent to processing, they pass through the sedimentation chamber 11, where the air is separated from the waste, which is transferred through the shutter 12 to conveyer 13, and further to the receiver hopper of the plant 14. Air cleaned by filter 15 from the impurities is emitted to the atmosphere.
It is reasonable to use turbo blowers as the air flow generators in the pneumatic transport systems for waste disposal. Based on the comparison between the calculated thresholds of the pressure differential variations and expenses caused by operation of the transportation pipeline branches with the available air blowers performance parameters, their quantity is determined in the pneumatic transportation system [1-10].

Combined suction-discharge unit encompasses the advantages of both suction, and discharge systems. They use the suction-type devices that ensure the intake of the DSW and removal of bad odor simultaneously from multiple waste doors; in the discharge branch of the pipeline, the DSW is carried by the boost pressure with rather high concentration to significant distance.

Main source parameters for calculation of the waste disposal systems are the annual and daily performance of the system, process flow scheme of the system, equipment package, transportation pipeline diameter, geometric properties, transportation pipeline branched grid structure, daily volume of the DSW accumulation in each of the concentrator shaft, and the DSW aerodynamic properties [11].

Annual performance of the pneumatic transportation system is determined from the annual DSW accumulation per person and the population of the residential micro region. Annual performance of the system is used to determine its economic efficiency.

Based on the maximum daily performance of the pneumatic transportation system, operation modes are calculated, process equipment is selected and designed, permissible DSW accumulation rates are determined according to the regional daily average norms.

Important source parameters for calculation are the geometric properties and structure of the system's transportation pipeline grid structure.

Pipeline grid should be placed onto the micro district master plan with connection of all residential buildings and public buildings to it with regard of the infrastructure-specific circumstances. After elaboration of the transportation pipelines grid scheme, the length of each branch, quantity of the DSW intake nodes on each branch, quantity and location of the DSW open collection points near the public buildings, air induction valves, and quantity and location of the transport pipeline branches shutters are determined. With regard of the residential buildings floors number and the public buildings purpose, maximum daily volume of accumulated DSW in each of the shaft concentrator should be determined.

Research has demonstrated that for reliable functioning of the DSW pneumatic transportation, the suction branch pipes diameter shall stay within 400-500 mm, and the same for the discharge pipes - 500-600 mm. Air flow speed in the pipes should not be less than 24-28 m/s.

After the source data acquisition and source parameters determination, aerodynamic calculation of the DSW pneumatic transportation process should be accomplished in all pipeline branches, with determination of the required pressure differentials and air consumption [12, 13].

Total pressure loss during the DSW transportation through the pipeline, \( \Delta P_m \), is determined using the Gasterstadt formula [14] with regard of the air density change along the pipeline length:

\[
\Delta P_m = (\Delta P_l + P_d \cdot \sum \xi_{z1})(1 + \mu K) + P_{do} \cdot \sum \xi_{z0-1} + \Delta P_r + \Delta P_{th},
\]

where \( \Delta P_l \) - pressure loss in the calculated pipeline branch when clean air is moving through it; \( P_d \) - air flow average dynamic pressure in the transportation section; \( \sum \xi_{z1} \) - sum of the pipeline branch local resistance coefficients on the transportation section; \( K \) - pneumatic transportation coefficient; \( P_{do} \) - air flow dynamic pressure in the branch starting section; \( \sum \xi_{z0-1} \) - sum of the local resistance coefficients on the branch starting section; \( \Delta P_l \) - pressure loss for acceleration of the DSW particles after they enter into the pipeline; \( \Delta P_{th} \) - pressure loss in the process equipment of the DSW collection central station and pipelines inter-connecting this equipment;

\( \Delta P_l \) may be determined using the formula:

\[
\Delta P_l = P_v (1 - C),
\]
where \( C = \sqrt{1 - 2\lambda \frac{l}{D} \frac{P_{do}}{P_v}} \) \( \cdots \) (1)

\( P_{do} = \frac{\rho_v V^2}{2} \); \( l \) and \( D \) - pipeline length and diameter; \( P_v, \rho_v \) - external air pressure and density; \( V \) - air flow speed; \( \lambda \) - pipeline hydraulic resistance coefficient (\( \lambda = 0.01-0.02 \)).

Average dynamic pressure equals to:

\[ P_{dc} = P_{do} \frac{(1 + C)^3}{8C^2} \] \( \cdots \) (2)

Pressure loss in the process equipment and pipelines may be calculated using the formula:

\[ \Delta P_{th} = \left( \lambda \frac{l}{D} + \sum \xi_i \right) \cdot P_{dt} \] \( \cdots \) (3)

where \( \lambda \) - pipeline hydraulic resistance coefficient; \( P_{dt} \) - air flow average dynamic pressure in the DSW hub station pipelines:

\[ P_{dt} = \frac{P_{dc}}{C} \] \( \cdots \) (4)

\( \sum \xi_i \) - sum of process equipment local resistance coefficients.

Pressure loss for the DSW particles acceleration is determined using the formula:

\[ \Delta P_t = P_{do} \cdot \mu \cdot \frac{(1 + C^2)}{2CV} \] \( \cdots \) (5)

Average air mixture mass concentrations \( \mu \) in the transport pipeline suction branch are expressed by the following relationship:

\[ \mu = \frac{\sigma \cdot N \cdot n \cdot \rho_m}{T \cdot Q_o \cdot \rho_o} \] \( \cdots \) (6)

where \( \sigma \) - DSW accumulation norm per person per day; \( N \) - average quantity of residents per single shaft concentrator; \( n \) - quantity of shaft concentrators in the calculated branch; \( T \) - duration of the branch's all shaft concentrators unloading:

\[ T = t \cdot n, \] \( \cdots \) (7)

\( t \) - average time of the single shaft concentrator unloading cycle; \( Q_o \) - air flow rate in the beginning of the pipeline; \( \rho_m \) - average density of the material being transported; \( \rho_o \) - air density.

Pneumatic transport coefficient \( K \) is determined by the following relationship:

\[ K = K_s \left( 1 + \frac{1}{F_w^*} \right) \] \( \cdots \) (7)

where \( K_s \) - coefficient of DSW particles sliding on the pipeline walls; \( F_w^* \) - Froude number [15].

Average sliding coefficient of the DSW particles mass being transported is calculated from their fractional and morphological composition, and equals to, for example, 0.2-0.5 (timber), 0.3-0.7 (glass), 0.06-0.08 (PTFE).

3. Conclusions
1. For DSW disposal under urban conditions, it is proposed to use the combined pneumatic transport units of suction-discharge action principle.
2. Combined pneumatic transportation unit allows to:
2.1. increase the DSW transportation distance, which makes it possible to deliver the DSW from the collection location to the processing location;
2.2. reduce the need in dedicated garbage trucks by 70-80%, which will provide positive effect for the ecology and traffic in the city;
2.3. ensure the DSW collection and transportation under any weather conditions and under extreme conditions (for example, in winter, when the streets and outdoor areas are overloaded with snow).
3. Method for selection and calculation of basic structural and process parameters has been provided for the suction-discharge pneumatic transport unit.

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