Dedicated to Professor Dr.-Ing. E. Bahke on his 65th birthday

Increase of the Suction Head by Means of the "Air-Lift" Method

M.Y. Dedegil, Germany

Summary

The use of suction methods for cleaning operations in inaccessible holes has many practical advantages. A major difficulty is the limited suction depth which can be achieved in normal use, this being controlled by the atmospheric pressure, allowing only 10 m suction head in the case of water.

The addition of air to the material in the "air-lift" method allows greater depths to be achieved. The present article reviews the underlying principle and limitations of the "air-lift" technique.

List of symbols

A	cross-section of the air tapping	m²
g	acceleration	m/s²
H_s	suction length	N/m² (mWS)
K	filter constant	Ns/m⁵
n	constant	—
p_0	atmospheric pressure	N/m²
p_T	absolute pressure in the tank	N/m²
$\dot{V}_w$	volume flow rate of water	m³/s
$\dot{V}_L$	volume flow rate of air through the filter	m³/s
$\dot{V}_{Lo}$	volume flow rate of blower at 1 bar and 20 °C	m³/s
Δp_1	pressure difference for air-sucking before transport	N/m²
Δp_2	pressure difference for air-sucking during transport	N/m²
Δp_F	pressure loss of the filter	N/m²
ϱ	density of the mixture to be sucked	kg/m³
ϱ_L	air density	kg/m³
β	contraction coefficient of the air tapping	—
ξ	drag coefficient of the air tapping	—

1. Introduction

For the cleaning of sewer systems and deep boreholes in many cases suction operation is the only practicable method because:

— the lowering of a pressure pump with its driving-motor is rather difficult and expensive or
— the cross-sections are too small for it or
— solids carried in the water cause heavy pump wear.

The suction head, however, is limited by the atmospheric pressure so that theoretically water can be sucked up only from a maximum depth of about 10 m, and high-density mixtures only from smaller depths.

If losses due to friction and to acceleration are disregarded, the suction head H_s as a function of absolute pressure in the tank is:

$$H_s = \frac{p_0 - p_T}{\varrho \cdot g} \tag{1}$$

where g is the acceleration due to gravity and ϱ the density of the material that is to be sucked up. Since the pressure difference achievable ($p_0 - p_T$) is limited to 1 bar and since g is constant, the suction head H_s can be increased only be adding a lighter component, for instance air, and thus diminishing the density ϱ of the mixture to be sucked.

2. The WOMA Suction Device

On behalf of the WOMA company of Duisburg and with the support of the AIF a suction device operating according to this principle was tested and developed at the Institute for Conveying Technology, Department of Fluid Transport, at the University of Karlsruhe.

The method of operation of this system is explained in Fig. 1. The bottom of the vertical conveying pipe (5) is immersed into the liquid to be sucked up. At its top it opens out into a tank (1), in which a blower (3) generates a partial vacuum. The water level in the pipe rises by H_s according to Eq. (1) and corresponding to the vacuum. On the right hand side in Fig. 1 pressure conditions are plotted for different operating conditions. Outside the pipe there is atmospheric pressure up to the water level. In the water itself the pressure increases linearly with the depth of the water. In the pipe, however, there is a constant partial vacuum p_T up to the internal water level, as in the tank. The pressure in the pipe increases with depth along straight line (a) so that at the bottom of the pipe, internal and external pressure are equal. Above the external water level the pressure inside the pipe is lower than atmospheric pressure.

If now, below the internal water level, a tapping in the pipe wall is opened, the pressure difference Δp_1 causes air to flow

Dr. Ing. M. Yavuz Dedegil, Institute for Conveying Technology, Department of Fluid Transport, Hertzstr. 16, D-7500 Karlsruhe 21, Federal Republic of Germany

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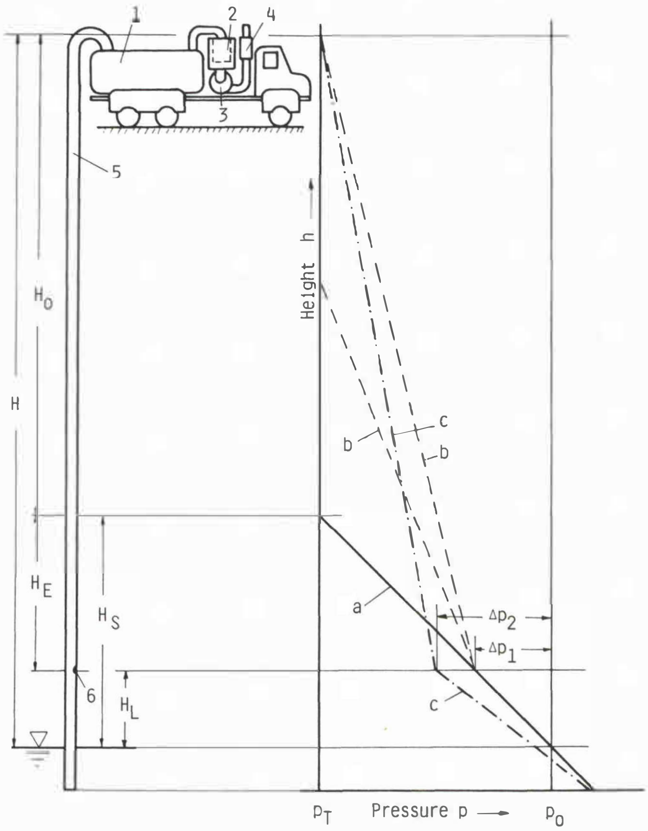

Fig. 1: Schematic sketch of the sucking-device and of the pressure distribution in the conveying pipe under different operating conditions.
a) Vacuum in the tank, air tapping closed.
b) Air is sucked in, the quantity is not sufficient for transport.
c) Idealized pressure distribution during transport.

1 Tank
2 Filter
3 Blower
4 Silencer
5 Conveying pipe
6 Suction hole

into the pipe and to flow upwards inside the pipe. Above the air tapping there is an expanded water-air-mixture to be found, and the pressure curve shifts from a to b as a consequence of the lower average density of the mixture.

With constant pressure inside the tank and identical geometry, the expansion of the mixture-column depends on two values:

a) The initial water column H_E above the air tapping: The bigger H_E, the smaller are the amounts of air that are necessary to lift the water up to the tank. The air tapping, however, cannot be located arbitrarily, because in that case the pressure difference Δp_1 which is necessary for sucking in the air would tend to zero. The location of the air tapping must be chosen so that H_E becomes as large as possible but that a sufficient pressure difference Δp_1 is maintained.

b) The volume flow rate of air, $\dot{V}_L$ which depends on the cross-section A of the tapping and on the pressure difference Δp_1 resp. Δp_2, according to Eq. (2)

$$\dot{V}_L = A \cdot \beta \sqrt{\frac{2 \cdot \Delta p_1}{\varrho_L} \cdot \frac{1}{1+\xi}} \tag{2}$$

with:

ϱ_L = air density
β = contraction coefficient
ξ = pressure-loss coefficient of the tapping

The cross-section of the air tapping must be calculated in such a way that the volume flow rate of air that is necessary for transport cannot be sucked in at the original pressure difference Δp_1 but only at a higher pressure difference Δp_2.

Only in this way can water be sucked into the pipe and conveyed up to the tank by means of the resulting additional pressure difference ($\Delta p_2 - \Delta p_1$). Above the air tapping there is a pressure distribution which is depicted ideally in Fig. 1 as two parts of a straight line (c).

This qualitative explanation of the operating principle shows that besides the selection of the blower data according to lifting height H and pipe diameter D also size and position of the air tapping are important for successful operation.

The transport principle is nothing more than air-lifting. The characteristics and mathematical basis of this procedure have already been described in several publications [1,2].

3. Theoretical Considerations

In the following the influence of different parameters on the transport curves $\dot{V}_w = f(\dot{V}_{Lo})$ will be explained by means of computed curves.

Fig. 2 shows the influence of the water column H_E above the tapping with H_s = 5 m, D = 155 mm and H = 15 m.

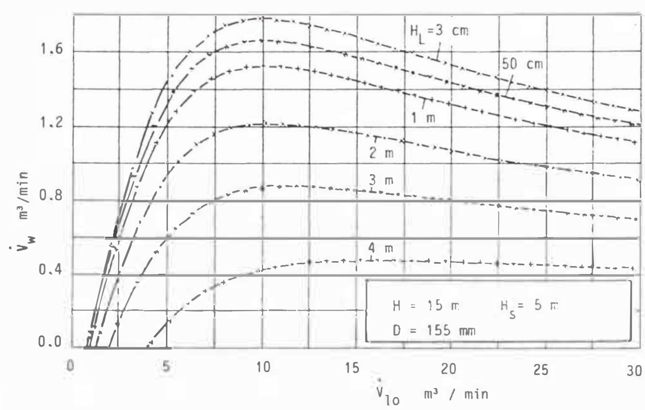

Fig. 2: Influence of the position of the air tapping above the external water level on the transport curves

If the air tapping is positioned extremely deep (H_L = 3 cm), the discharge volume at first rises very steeply, reaches a maximum at $\dot{V}_L$ = 10 m³/min and then decreases with increasing volume flow rate of air. The higher the air tapping is located, the smaller are the discharge volumes achieved. At the same time the maximum of the air flow rate shifts to higher air volumes. As experience has proved, the air hole should be located in this case at about 10 to 50 cm above the external water level, so that the discharge volume remains the same and relatively small air tappings for the sucking of air are sufficient.

Fig. 3 shows the influence of the lifting height H with constant suction height H_s = 5 m and H_L = 50 cm and with a pipe diameter of D = 155 mm.

If the lifting height increases, the maximum possible discharge volume decreases with the discharge maximum shifting to higher air volumes.

Fig. 4 shows the influence of the suction height H_s on the discharge volume with H = 15 m and D = 155 mm, the air tapping being supposed at 50 cm above the external water level.

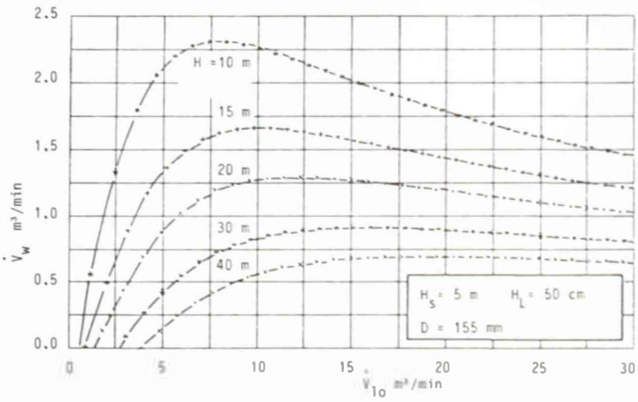

Fig. 3: Influence of the lifting height on the transport curves

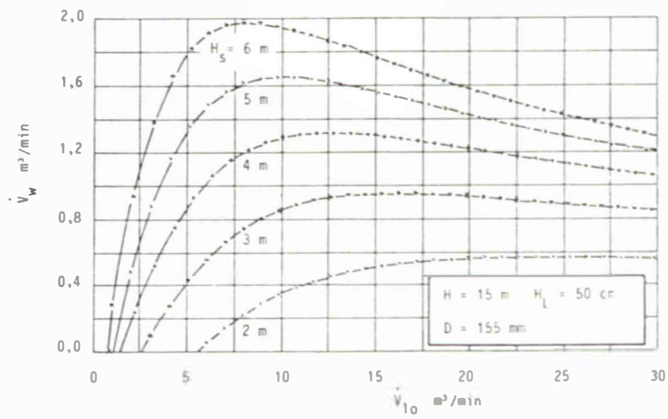

Fig. 4: Influence of the suction height on the transport curves

4. The Influence of Filter Drag

Usually in the suction-devices a filter (2) between tank and blower, and a silencer (4) after the blower are installed. Furthermore, there are non-return flaps and valves in the pipe.

All these built-in components cause pressure losses which increase with the volume flow rate of air and cause a decrease of the effective suction length and thus of the discharge capacity.

Since the air pipes in the system investigated are comparatively short, the biggest pressure loss will be expected in the filter. The pressure loss in a filter depends on the quantity and on the nature of the particles that are to be precipitated, on the volume flow rate of air and on its degree of pollution, i.e., the filter drag is a function of time [3, 4].

Moreover, the drag of a filter that is designed for dry air increases very much if the air not only carries solids but also water droplets thus wetting the filter or even covering its surface partially with mud.

No information could be found in the literature about the calculation of the filter drag under these circumstances. With constant surface, permeability and size of the pores and constant kinematic viscosity of the passing fluid the filter drag Δp_F is calculated according to

$$\Delta p_F = K \cdot \dot V_L \qquad (3)$$

with K being constant with the dimension (Ns/m⁵). In order to take into account the wetting of the filter the pressure loss is supposed to grow additionally with the expression $(\dot V_W/\dot V_L)^n$, i.e., the filter drag behaves according to Eq. (4)

$$\Delta p_F = K \cdot (\dot V_W/\dot V_L)^n \cdot \dot V_L \qquad (4)$$

By means of the tests performed the values $K = 35$ Ns/m⁵ and $n = 0.7$ were determined.

In Fig. 5 the calculated discharge curves, in which a diminution of the original suction length of 5 m by the filter drag Δp_F according to Eq. (4) was taken into account, are compared with the points obtained experimentally. It can be seen that the discharge volumes achieved are now much smaller than the previously calculated valves. The curves also change in shape, so that the curves around their maximum are much flatter.

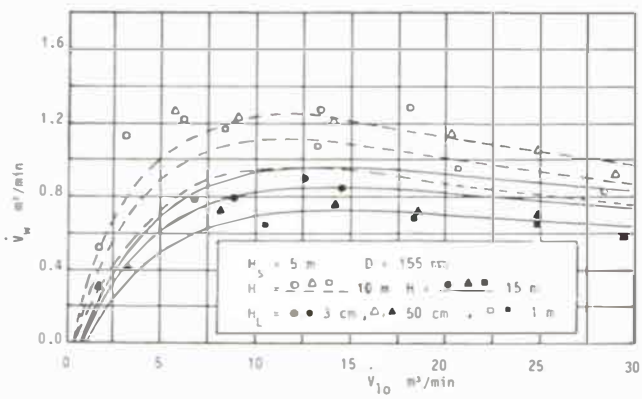

Fig. 5: Comparison of the test results with the transport characteristics calculated according to Eq. (4), which takes into account the drag coefficient of the filter.

5. Conclusions

The results of these tests can be summarized as follows:

— The tapping for air-sucking should be located in such a way that H_E is as large as possible, but the cross-section of the tapping which is calculated from Equation (2) with Δp_2 does not exceed 1/4 of the pipe diameter.

— Flow drags between tank and blower must be kept as low as possible and taken into account in the calculation.

— The discharge quantity can be increased only up to a maximum that can be calculated. Any further increase of the air volume leads to a decrease of the discharge volume.

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