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OPTIMUS-EP STORAGE RESERVOIR WITH A VACUUM CHAMBER FILLED BY A SYSTEM OF SUCTION AND FORCE PUMPS

Hydraulic bases of the operation of an OPTIMUS-EP reservoir belonging to a new group of energy-saving reservoirs in sewerage systems are presented. This reservoir has a vacuum chamber being filled with sewage by a controlled system of suction and force pumps. The processes of a vacuum chamber filling and emptying are controlled by a regulator allowing the air to be released into the atmosphere when a chamber is being filled with sewage and a constant sewage outflow to be kept when a chamber is being emptied. A reservoir is fully capable of equalizing sewage outflow. Drawing of sewage from a vacuum chamber ensures optimal time of pump work.

1. INTRODUCTION

In a new generation of gravitation-vacuum reservoirs presented in 1998 [1], sewage is stored in vacuum chambers located above a level of sewage inflowing into a reservoir. Sewage is accumulated by vacuum pumps which can be termed "vacuum turbines" of big volumetric delivery but small negative pressure, usually lower than 0.5 at. A vacuum pump installed according to a basic scheme ensures sewage vacuum accumulation at a given maximal flow capacity of sewage assumed to be stored. Sewage of smaller flow capacities are accumulated with a regulator which aerates a chamber when a vacuum pump works with its full delivery. A vacuum chamber, whose bottom is on the level of a free sewage inflow to a reservoir, may reach the height of 4.50 m. This results from capillary flow of air stream and reduction of liquid evaporation under negative pressure conditions.

Regulators control the rise of a sewage level in a vacuum chamber during its filling and the rate of sewage level lowering during emptying a vacuum chamber which then need not to be mechanically closed. Operation of a regulator consists in control of air

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flow from the atmosphere into a vacuum chamber. A portion of delivered air depends on the position of a sewage level which stimulates an inside diameter of an intake regulator. Gravitation-vacuum reservoirs with vacuum pumps are hydraulically effective but a constant and energy-consuming work of pumps even at small flow capacities forced the researchers to search for energy-saving solutions. This was achieved through vacuum sewage accumulation by vacuum pumps in three-chamber reservoirs MIRUS-ES [3] and CONSES-ES [4] as well as in the reservoirs COMMODUS-EP, MIRUS-EP and CONSES-EP where vacuum chambers are filled due to the systems of suction and force pumps [5].

2. COMPONENT PARTS OF A RESERVOIR AND HYDRAULIC BASES OF ITS OPERATION

An OPTIMUS-EP reservoir is identical to a MIRUS one (figure 1). It has three chambers – two retention chambers, i.e., a gravitation one (KRG), and a vacuum one (KRP) and one gravitation flow chamber (KP). A reservoir is equipped with a system of suction and force pumps (MP) with a suction pipe (PS) inside a gravitation chamber. A force pump (PT) is tightly inserted into a vacuum chamber. A system of pipes

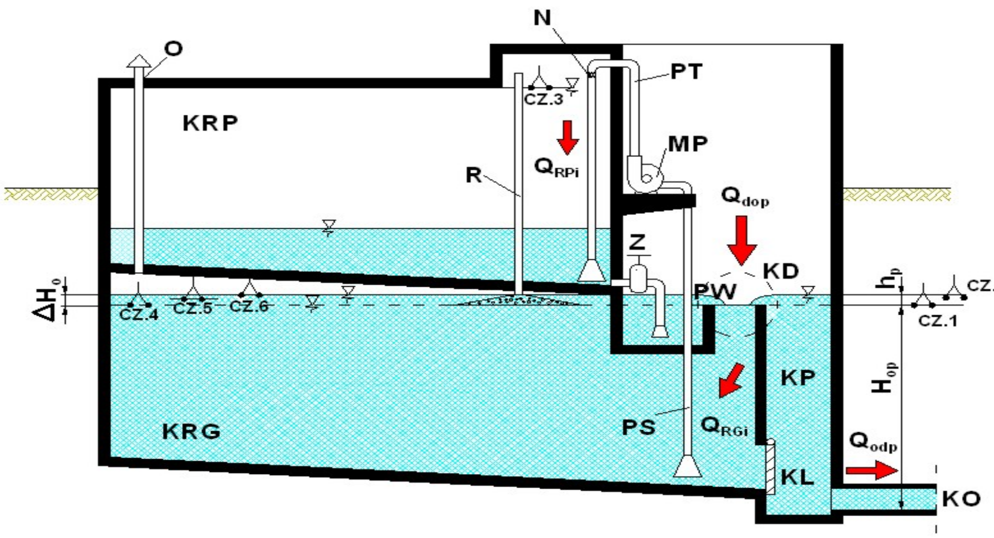

Fig. 1. Scheme of a three-chamber reservoir OPTIMUS-EP

consisting of suction and force pumps has an aerating safety device (N) preventing an uncontrolled siphon-like motion from a vacuum chamber to a gravitation one (figure 2). A gravitation chamber could be filled within a range of ΔH_0 and this decides how widely an air intake of a regulator (R) is open. A regulator is shaped as a perforated side surface of a cone. A deaeration pipe (O) is designed to enable air to escape to the atmosphere from both retention chambers when they are being filled with sewage. A vacuum chamber is being emptied through a gate (Z) installed on a stub pipe coming from a bottom zone of a vacuum chamber to a flow one.

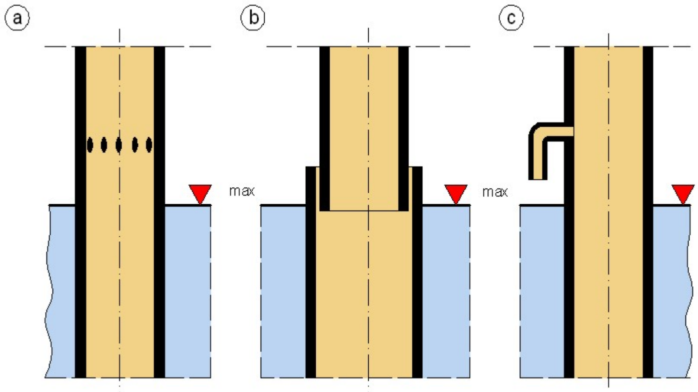

Fig. 2. Ways of aeration of a force pump pipe

A gravitation chamber is filled with sewage by means of a tower overfall with a crest (H_{0P}) situated above a bottom of a flow chamber. There is a flap gate (KL) at a bottom zone of a wall separating two gravitation chambers: a retention chamber and a flow one. Hydrostatic pressure opens a flap automatically which enables sewage outflow from a gravitation chamber to a flow chamber when a reservoir is being emptied. When a vacuum chamber is full or when the flow capacity of sewage inflowing to a reservoir is below the value of reduced flow capacity, a system of pumps is switched off and a gate (Z) is opened. A gate is installed on a pipe segment connecting a vacuum chamber with a suction pipe (PS) of a pump system.

Sewage is stored in a vacuum chamber of a reservoir until it fills and then pumps are switched on and they transport sewage from a gravitation chamber to a vacuum one. Pumps should be controlled in a way ensuring their continuous work till a process of sewage accumulation, corresponding to a sewage inflow hydrograph, is completed. Pumps are stopped when a vacuum chamber is full or when there is no sewage inflow to a reservoir. Then a gate (Z) is opened and a regulator controls the emptying of a vacuum chamber. Pumps are also switched off when the sewage flow capacity Q_{Ri} is so small that at a minimal pump capacity such that $Q_P > Q_{Ri}$ sewage stored in a gravitation chamber reaches a level lower than a maximal one by ΔH_0 value. However, in this case, a gate (Z) is not opened.

A vacuum chamber is tight and separated from the atmosphere and while it is being filled a regulator (R) releases air to the atmosphere [2]. The same regulator (fig-

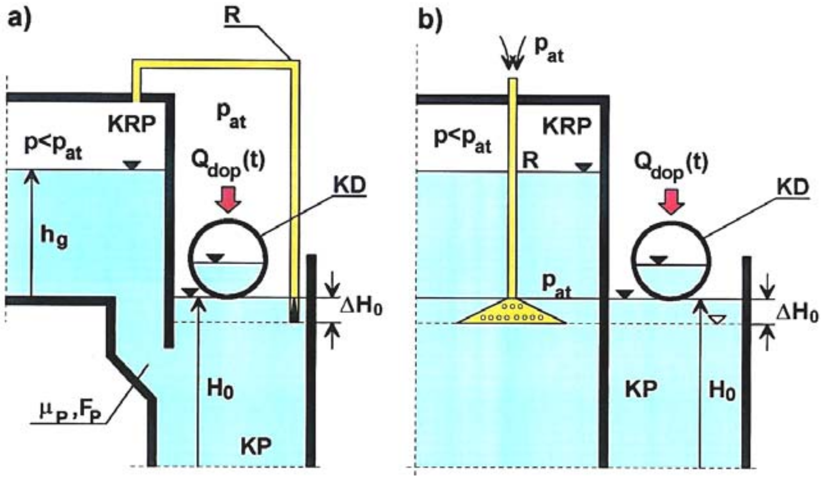

Fig. 3. Basic schemes of regulators controlling processes of filling and emptying vacuum chambers in a retention reservoir

ure 3) keeps constant sewage outflow when a chamber is being emptied. Outflow capacity is close to a reduced flow capacity.

3. CONTROL OF A SYSTEM OF SUCTION AND FORCE PUMPS IN A RESERVOIR OF OPTIMUS-EP TYPE

Pumps are switched on when a gravitation chamber is full. A designer determines a sewage layer ΔH_0 (figure 1) which has to be pumped from a gravitation chamber into a vacuum one. Pumps should be controlled in such a way that assures a proper sewage accumulation in a vacuum chamber and this will be achieved when a sewage volume pumped over a period of time is approximately the same as flow capacity of currently inflowing sewage. Energy consumed during operation of pumps will be considerably reduced. Such a way of controlling all pumps consists in their switching on/off by means of sensors detecting the levels of sewage accumulated in the gravitation and flow chambers. These sensors can be placed in a gravitation chamber (KRG) within ΔH_0 range; for example, 3 of them (the 4th, the 5th and the 6th sensors) for two pump units (n = 2). Each flow chamber (KP) should always be equipped with 2 sensors: the first one – on an overfall crest level (PW), the second one – slightly below $H_{0P} + h_P$ level. The third sensor controls the operation of vacuum chamber (KRP) on a level of its maximal capacity. The sensors can be classified on the basis of their operation in the following way:

Sensor no. 1 switches pumps on and is placed under a sewage level. When sewage flow halts and a flow chamber is filled below an overfall crest, a sensor switches pumps off and opens a gate flap to empty a vacuum chamber.

Sensor no. 2 is placed under a sewage level in a flow chamber and it switches on all pump units when a gravitation chamber is full and after sensor no. 6 begins its action. If sensor no. 2 is above a sewage level it may switch on only one pump.

Sensor no. 3 switches off pumps when a vacuum chamber is full and opens a gate flap to empty a vacuum chamber.

Sensor no. 4 responds when sewage level in a gravitation chamber is lowered by the value of ΔH_0 and switches off all pump units, but it does not open a gate flap. Pumps can be switched on again, provided that a chamber is refilled which means that sensor no. 6 ought to be active.

Sensor no. 5 is placed in a gravitation chamber by 0.5 ΔH_0 below a maximal sewage level and it switches off one of two pump units.

Sensor no. 6 switches on all pump units (n = 2) if sensor no. 2 is submerged beneath a sewage level in a flow chamber. If sensor no. 2 is above a sewage level, sensor no. 6 switches on only one pump.

In the example with two pump units (n = 2) and full gravitation chamber, both pumps are switched on simultaneously only when sewage flow capacity $Q_{\mathrm{dop}(t)}$ is big enough (for example, $Q_{\mathrm{dop}(t)} \geq 0.75\ Q_M$). Sensors no. 2 and no. 6 have shorted compacts since they are immersed in sewage.

In a calculation case, the total pump capacity nQ_P is slightly bigger than the assumed sewage flow capacity Q_R:

$$nQ_P \geq Q_R = Q_M - Q_0\,, \tag{1}$$

where:

Q_P – the capacity of one pump unit,

Q_M – a maximal sewage inflow capacity resulting from a calculation hydrograph,

Q_0 – a chosen maximal sewage outflow capacity – called the reduced flow,

Q_R – a determined maximal flow capacity of accumulated sewage.

When $Q_{\mathrm{dop}(t)} < Q_M \leq nQ_P$, a flow capacity Q_{Ri} of accumulated sewage is smaller than the maximal flow Q_R and according to the example a total capacity of pumps will cause the lowering of a sewage level in a gravitation chamber by $\Delta H/n = \Delta H/2$ and consequently one pump will be switched off by sensor no. 5. If sewage inflow to a reservoir is continuously halted, a sewage level in a gravitation chamber lowers and when it reaches a level by ΔH_0 lower than a maximal one, sensor no. 4 switches off pumps. A process of sewage accumulation in a vacuum chamber will be resumed only when a gravitation chamber is full again and sensor no. 1 is shorted. An approximate work time of two pump units is:

$$t_i = \int_{H_{RG}}^{H_{RG}-0.5\Delta H_0} \frac{-F_{KRG}}{\left(Q_{\text{dop}(t)} - \frac{Q_0}{\sqrt{H_0}}\sqrt{h_0} - 2Q_P\right)} dh_g\,. \tag{2}$$

A pump will be switched off again when $Q_P > Q_{Ri}$ and when a sewage level in a gravitation chamber is lowered by ΔH_0. Here, the work time of pump units is estimated as:

$$t_2 = \int_{H_{RG}-0.5\Delta H_0}^{H_{RG}-\Delta H_0} \frac{-F_{KRG}}{\left(Q_{\text{dop}(t)} - \frac{Q_0}{\sqrt{H_0}}\sqrt{h_0} - Q_P\right)} dh_g\,. \tag{3}$$

In equations (2) and (3) there are:

F_{KG} – the surface of free sewage level in a gravitation chamber,

h_g – the sewage depth in a gravitation chamber within $H_{KG} \geq h_g \geq H_{KG} - \Delta H_0$ interval,

H_{RG} – a maximal sewage depth in a gravitation chamber,

Q_{Ri} – the flow capacity of accumulated sewage:

$$Q_{Ri} = Q_{\text{dop}(t)} - Q_{0i}\,, \tag{4}$$

where:

$Q_{\text{dop}(t)}$ – an instantaneous sewage inflow capacity,

Q_{0i} – an instantaneous sewage outflow capacity.

An instantaneous inflow of sewage $Q_{\text{dop}(t)}$ results from particular conditions of surface run-off in a basin attached to a retention reservoir under consideration, while an instantaneous outflow Q_{0i} can be determined according to the following formula:

$$Q_{0i} = \frac{Q_0}{\sqrt{H_0}}\sqrt{h_0}\,, \tag{5}$$

where:

$Q_0 = \mu_0 f_0 \sqrt{2gH_0}$ – a reduced flow capacity obtained when a flow chamber is filled up to the level of $H_0 = H_{0P} + h_P$ (figure 1) at an outflow hole of the surface f_0 and the capacity coefficient μ_0,

h_0 – an instantaneous sewage depth (m) in a flow chamber; during sewage accumulation this value varies within $H_0 \geq h_0 > H_{0P}$ interval.

The presented way of control of two pump units is only an example of the methods leading to energy saving and should not be treated as the only solution. The work of a pump system may be controlled and carried out in other ways, but always energy saving should be achieved.

4. HYDRAULIC PARAMETERS OF A RESERVOIR

Filling a flow chamber to a depth H_{0P} completes a phase of a sewage flow through a reservoir. In this phase, sewage flow capacity reaches:

$$Q_{0P} = \frac{Q_0}{\sqrt{H_0}} \sqrt{H_{0P}} \,. \tag{6}$$

When a flow capacity of sewage increases, sewage is accumulated in a gravitation chamber of a reservoir. A sewage level in a flow chamber is raised to $H_{0P} < h_0 \le H_0$, the outflow from a reservoir becomes $Q_{0P} < Q_{0i} \le Q_0$ and a gravitation chamber is being filled with sewage by means of a tower overfall:

$$0 < Q_{Ri} = \boxed{\frac{Q_R}{h_P^{3/2}} h_{Pi}^{3/2}} \le Q_R = Q_M - Q_0 \,, \tag{7}$$

for $h_0 - H_{0P} < \boxed{h_{Pi}} \le H_0 - H_{0P} = h_P$, where: $H_{0P} < h_0 \le H_0$.

In the reservoir described, at first its gravitation chambers are filled – a gravitation chamber after a flow one. In this phase of a reservoir operation, a constant outflow from a reservoir can be kept if a continuous sewage accumulation in a reservoir is ensured. Such an outflow takes a value:

$$Q_{0P} < Q_{0i} \le Q_0$$

or:

$$\frac{Q_0}{\sqrt{H_0}} \sqrt{H_0 - h_P} < \boxed{\frac{Q_0}{\sqrt{H_0}} \sqrt{h_0}} \le Q_0 \tag{8}$$

for $H_{0P} < h_0 \le H_0$.

When a gravitation chamber is being filled and sewage inflow capacity temporarily drops to $0 \le Q_{\mathrm{dop}(t)} < Q_{0P}$, then it is impossible to maintain the outflow from a reservoir on the level given by equation (8) since a vacuum chamber is empty. When a gravitation chamber is full, then a system of suction and force pumps begins to fill a vacuum chamber. When a process of sewage accumulation is completed, a vacuum chamber may be entirely or partially filled with sewage. Then, a system of pumps is switched off, a release gate flap is open and a reservoir is being emptied. During the whole process of emptying a vacuum chamber a sewage outflow capacity is kept within the range given by equation (8). Incidentally, when an air intake of a regulator is opened during a vacuum chamber emptying, a gate flap may be closed. Here, the parameters of outflow controlled by a regulator are restored by adding sewage to a gravitation chamber through a tower overfall. This time the outflow from a reservoir is nearly equal to Q_0. Cyclic appearance of such a scheme of emptying a vacuum chamber is quite possible. If an inlet to a regulator is placed in a flow chamber (figure 3a), emptying a vacuum chamber can be fully controlled by a regulator. After a vacuum chamber is entirely emptied, both gravitation and flow chambers are being simultaneously emptied and the capacity of sewage outflow successively approaches 0.

5. FINAL REMARKS

The variability of flow capacity of sewage accumulated due to negative pressure in an OPTIMUS-EP reservoir is taken into account in a proper operation of pump units. In the solution presented, sewage is pumped from a gravitation chamber to a vacuum one which takes enough time and thus there is no need to switch pumps on again. This is ensured by a proper sewage volume, for example, 0.5 $\Delta H_0 F_{RG}$, to be transported by pumps to a vacuum chamber. Direct sewage transfer from a vacuum chamber to a flow one makes it possible to keep sewage outflow from a reservoir almost constant and nearly equal to a reduced value Q_0. This effect is achieved during emptying a vacuum chamber when a sewage inflow capacity temporarily drops below Q_0 or when there is no surface run-off in a river basin and hence no sewage inflow.

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ZBIORNIK RETENCYJNY CIECZY TYPU OPTIMUS-EP Z PODCIŚNIENIOWĄ KOMORĄ NAPEŁNIANĄ PRZEZ UKŁAD POMP SSĄCO-TŁOCZĄCYCH

Przedstawiono hydrauliczne podstawy działania zbiornika typu OPTIMUS-EP, który należy do nowej grupy energooszczędnych zbiorników o działaniu grawitacyjno-podciśnieniowym przeznaczonych do sieci kanalizacyjnych. Zbiornik ma podciśnieniową komorę retencyjną, wypełniającą się ściekami za pośrednictwem sterowanego układu pomp ssąco-tłoczących. Podciśnieniowa komora zbiornika jest napełniana i opróżniana przy współudziale regulatora. Umożliwia on odprowadzenie powietrza do atmosfe-

ry w czasie napełniania komory ściekami, a podczas jej opróżniania utrzymuje prawie stały odpływ ścieków ze zbiornika. Ma on pełną zdolność wyrównania odpływu ze zbiornika, a także zapewnia – dzięki czerpaniu ścieków z grawitacyjnej komory retencyjnej – optymalny czas działania poszczególnych jednostek pompowych.