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차세대 고효율 용존공기 부상공정(High Rate DAF)의 개발

Development of Dissolved Air Flotation Technology from 1st Generation to the Newest or 3rd One (Very Thick Microbubble Bed) with High Flowrates DAF in Turbulent Flow Conditions

H.J. Kiuru*

Dept. of Water and Wastewater Engineering, Helsinki University of Technology,
P.O. Box 02150, HUT, FINLAND

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Abstract

Dissolved air flotation (DAF), in which suspended solids are removed from water by means of micro-size air bubbles raising slowly up in water and lifting solids from water (smaller than those) attached onto the micro-bubbles as well as those (larger than solids) being attached on these, have been used in water and wastewater since 1920s. The dissolved air flotation technology was originally based on the laminar flow conditions prevailing in water to be treated, but the latest development in that technology has led now to a situation, in which the flow conditions may also be turbulent ones in the modern dissolved air flotation units. Despite of that, the flotation phenomenon used in this unit operation for removal suspended solids from water or wastewater is still the same.

Key words: Dissolved air flotation; creation of micro-bubbles; control of hydraulics; flow conditions; high flowrate DAF

주제어: 용존공기부상법, 미세기포 발생, 수리학적 제어, 유량조건, 고효율 DAF

1. DEFINITION OF DISSOLVED AIR FLOTATION IN WATER AND WASTEWATER TREATMENT

Dissolved air flotation DAF is a unit operation for removal of suspended solids from water in which particles are lifted up out of water by a large amount of air micro-bubbles attached onto those. These invisible bubbles (diameter less than 100μm) have been normally created by means of so-called dispersion water or high-pressure (40-70 mwp) water containing a saturated amount of dissolved air. The dispersion water, normally 5-15% of the amount of water to be treated by DAF, is fed into that in front of the flotation space in a DAF tank. There is a lot of different methods used in feeding the dispersion water

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*Corresponding author Email: heikki.kiuru@kiuru-rautiainen.inet.fi (Kiuru, H. J.)

into water to be treated by DAF as well as in distribution of air micro-bubbles released from the dispersion water into the whole mass of water to be treated by DAF.

Creating air micro-bubbles and mixing those into the water to be treated by DAF may be carried out also by injecting pressurised air to the suction size of a centrifugal pump which is used to lift water into a DAF unit. In this application, the total amount of water to be treated by DAF is pressurised to a clearly lower pressure (30-40 mwp) as the dispersion water is pressurized in the "normal" solution mentioned above. If the amount of air dissolved into the water to be treated by DAF is the same as then, when using a minor amount of dispersion water, the energy costs of both systems are almost equal, in practice. Systems based on the high-pressure dispersion water are mainly used, when treating water in a large scale.

When the high pressure of dispersion water or a clearly lower pressure of the total water flow to be treated by DAF containing an excess amount of air is decreased at once to the atmospheric one in which water will be treated, this excess air of dispersion water or that of the total amount of water to be treated by DAF, is released from if as gas forming micro-bubbles. It is essential that these micro-bubbles are mixed with the total amount of water to be treated just at the beginning of the DAF-unit. The total amount of air or that of dispersion water is depending on the concentration of suspended solids in the water to be treated by DAF. The normal amount of dispersion water mentioned above, is sufficient to remove effectively suspended solids from water up to a concentration of 400-500mg/l. When the concentration of suspended solids is higher than that, the amount of bubbles must be increased according to the concentration of suspended solids to be removed from water.

2. INTRODUCTION OF DAF TECHNOLOGY IN WATER AND WASTEWATER TREATMENT

Dissolved air flotation was taken in use at first in the dressing of ores as well as in the process industry at the end of 19th century. It is used for recovering of dressed ores as well as of other valuable raw materials from water suspensions for exploiting those in some industrial activities. The particles which are removed from water by DAF in these applications are of a commercial value and the target is recover those as effectively as possible. The efficiency of DAF in these applications is expressed as the recovery-rate of particles from water (g/l or kg/m^3. It is of a secondary importance only, if some of the wanted particles remain in the water after DAF. In the other words, the quality of water after DAF is not very important.

Dissolved air flotation was introduced in water treatment in 1920's The technical role of DAF in water and wastewater treatment is exactly the same as it is in the dressing of ores and process industry. But instead of the recovery of particles, DAF is used in water and wastewater treatment for purification of water by taking away particles from water as well as possible. The efficiency of DAF is then expressed as the concentration of particles(mg/l or g/m^3) left in the water after DAF. In this way, the reduction rate of particles or the removal efficiency of those (per cent) are of interest in water and wastewater treatment. The major interest is the quality of water after DAF.

Among the first DAF-systems used in water and wastewater treatment were the ADKA and Sveen-pedersen ones. The main feature or of these systems are the dimensions of their flotation tanks. Those are rather long, narrow and very shallow ones. Usually there is a vertical inlet shaft in the beginning of the tank which is as broad as the tank itself, Water to be treated by DAF is let onto the bottom of the inlet shaft in which the dispersion water also is let through few dispersion nozzles being located near the bottom of the shaft. There are turbulent flow conditions in the inlet shaft in which water is flowing upwards to the surface of water in flotation tank.

In this way, micro-bubbles having been released into water close to the bottom of the shaft will be mixed in the shaft rather evenly into water to be treated by DAF.

Water with micro-bubbles is then flowing almost horizontally in the flotation space of this kind of a DAF-system, because it is taken out of the system from the end of the shallow flotation space. There is an underflow wall in front of the long, narrow and shallow rectangular tank and clarified water is taken out near of the bottom of the tank. The flow rate of water in the flotation space is normally 2-3m^3/m^2 × h or m/h and in any case clearly less than 5m/h. There is only a very thin micro-bubble blanket below the water surface in the flotation tank, because the flow rate is very low and the direction of flow is only a little bit declined downward from a horizontal one. In many cases, there is no micro-bubble blanket at the end of the tank at all. This means that there is quite a large share of the tank at the end of it which is not in an effective use.

It is clear that there is almost no filtration effect of a micro-bubble blanket for the water to be treated in this kind of DAF-systems which can be called the 1st generation of DAF in water and wastewater treatment. This means that the attaching of micro-bubbles onto solids takes place mainly already in the inlet shaft of tanks. But when operating these systems with proper flow rates mentioned above, quite a high removal efficiency for suspended solids have been achieved, however, There still are some of this kind of DAF-systems in use to clarify process water for pulp and paper industry. A scheme of the Sveen-Pedersen DAF-system is presented in **Fig. 1.**

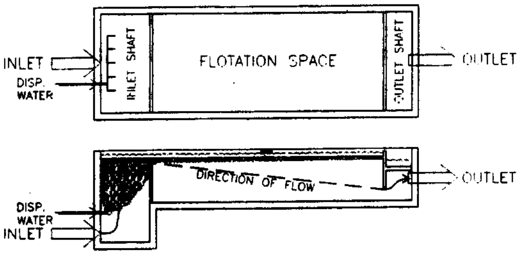

Fig. 1. A scheme of the Sveen-Pedersen DAF-system

3. INVASION OF DAF-TECHNOLOGY IN WATER AND WASTEWATER TREATMENT IN THE 1960'S AND 1970'S

Dissolved air flotation was taken largely in use for water and wastewater treatment during the 1960's and 1970's in the Scandinavian countries. The explanation to this was that dissolved air flotation is an overwhelmingly efficient unit operation for removal of light suspended solids created by coagulation and flocculation of humic substances from water by trivalent metal salts, when comparing it with the settling by gravity especially, if cold waters are treated. For instance in Finland, DAF has replaced almost totally settling as a water clarification operation in the surface water treatment since the beginning of the 1970's.

DAF-technology was remarkably developed during these decades at first in Sweden and later in Finland. The central role of hydraulics in the implementation of an effective DAF was started to understand step by step. The main process arrangements of DAF were not changed at first, but it was found out that, when higher flow rates of water than 5 m/h were wanted to use, the geometry of flotation tanks should be changed a lot. The tanks became clearly broader and deeper. Also the length of tanks was decreased clearly. It was understood that a tight uniform micro-bubble bed throughout the whole surface area of the tank is needed, if an effective removal of suspended solids was wanted to implement by DAF. There are also round flotation tanks having the same hydraulic idea in which the inlet shafts are located in the middle of the tanks.

The flowing direction of water in the flotation space was declined a lot more from the almost horizontal one toward the bottom of the tank by increasing the depth of the flotation space. In these, today conventional, DAF-systems, the angle of flow down from the horizontal level may be some 30-45°. In this way, the flow-rate of water in the flotation space of a DAF-tank could be in creased easily to 5-7m/h and even up to 10m/h at most. This resulted in an evenly tight micro-bubble bed below the water surface throughout a flotation tank. The thickness or depth of this micro-bubble bed may be some 30-50cm at the beginning of a tank. It decreases linearly, when going to the end of a tank being there often some 20-10cm only.

It is clear that the micro-bubble bed in the upper part of the flotation space has a clear filtration impact increasing the rate of the attachment of bubbles onto solids, because a major part of water to be treated is forced to flow through the bubble-bed. This kind of an application of DAF can be called the 2nd generation of it or the conventional ones. A scheme of it is in **Fig. 2.**

When talking about the development of DAF-technology, the probably most important step from the point of view of hydraulics has been the invention of flotation filter which took place in the late 1960's in Sweden. The idea for this combination of dissolved air flotation and rapid filtration in the same tank is based on a realization that the hydraulic load bearing capacity of a rapid sand filter is quite the same as that of DAF. Hydraulically this combination is an ideal one resulting in an exactly vertical flow of water from the surface of water in the tank directly downward to the filter bed covering the whole bottom of the flotation space. The whole surface of the filter bed in the flotation space is used for letting the clarified water out from the flotation space.

The flow resistance of the filter bed is so high that it equalizes the flow of water evenly throughout the flotation space, so that the vertical flow-rate of water downward is exactly the same everywhere in the flotation space. This means that there is a rather thick bubble bed in the upper part of the tank having an exactly horizontal lower surface. If the height of the flotation space above the filter bed is big enough, the flow rate of water in DAF as well as that in filtration may be easily 10-15m/h which, in turn, means that the thickness of mocro-bubble bed is 80-120cm. There is a clear deep-bed micro-bubble filter in the upper part of the flotation space and water is forced to flow through that micro-bubble filter. The role of this micro-bubble filter in removal of solids is probably much greater than that of mixing micro-bubbles with water to be treated in the inlet shaft of the tank.

The flow-rate of water in a flotation filter might be hydraulically at least 20-25m/h, but usually a rather low load bearing capacity of the normal sand filter for suspended solids is limiting the flow-rate, so that it cannot be more than 15m/h without causing a too rapid growth of the filter head loss. This means that flotation takes place clearly in the laminar flow conditions. A scheme of the conventional rectangular flotation filter is presented in **Fig. 3.**

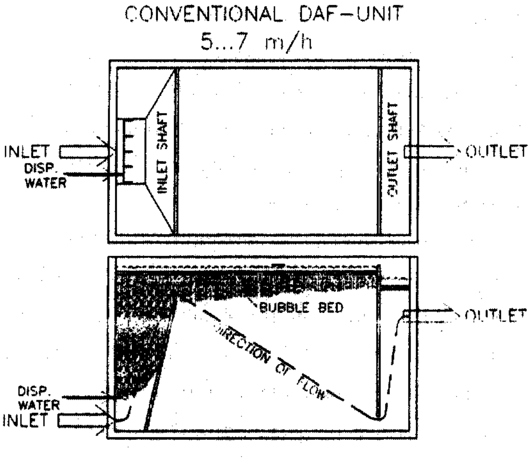

Fig. 2. A scheme of 2nd generation of DAF

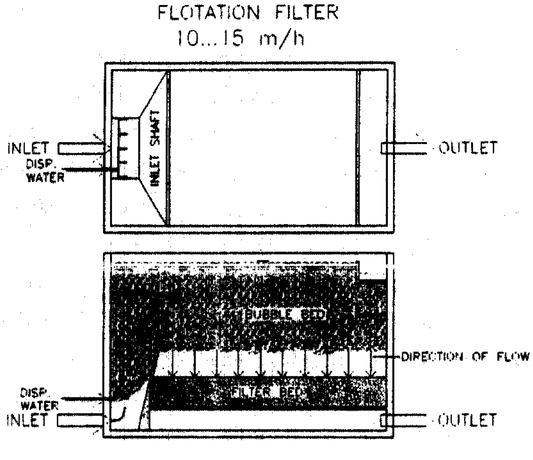

Fig. 3. A scheme of the conventional rectangular flotation filter

4. DEVELOPMENT OF HIGH-RATE DAF-TECHNOLOGY WITH TURBULENT FLOW CONDITIONS

It is more than probable that the hydraulic working principle of flotation filters has been exploited, then the 3rd generation of DAF-systems have been developed during 1990's. When the target has been to increase the flow-rate of DAF units over that which is possible in practice by using flotation filters, it has been only a consequent measure to replace the sand filter by some mechanical structure which is able to control the flow of water in the flotation space as well as the filter can do, but which has no clogging problem as the filter has.

It has been believed until to these days that flotation can be operated only in the laminar flow conditions. This is to say that the maximum flow-rate of water could be at most about 25m/h in the flotation space of a DAF-system, if the hydraulics are wanted to control. It is well known that, when the flow-rate of water exceeds that level of velocity, the flow conditions will inevitably change from the laminar ones to the turbulent conditions. The task has been to solve, how to control the flow of water in the turbulent flow conditions, so that the flotation phenomenon might take place properly. In the other words, the problem is, how all of the micro-bubbles could rise surely up to the free surface of water in the flotation space in which the water to be treated flows down with a high velocity form the surface toward the bottom of that space causing a lot of turbulence in the flotation space.

It is obvious that there are different solutions in order to try to answer to this question. Among the simplest ones is that which has been developed by Mr. Oiva Suutarinen of Rictor Ltd in Finland. Because Mr. Suutarinen will have his own presentation concerning his turbulent flotation just after this one, the common principles of that high-rate flotation are only presented here.

When the flow-rate may be 25-40m/h or even more, it is clear that the geometry of the flotation tank must be chosen according to this hydraulic requirement. The natural flowing direction of water in this case is vertical or down from the free surface of water directly to the bottom of the flotation tank. This is why, the horizontal cross-section of the flotation space is a square and the inlet shaft is located on the one side of the square flotation space. Taking in account the flow-rate of water to be treated by DAF means that the depth of the flotation space shall be big enough, because the micro-bubbles will be driven the deeper, the higher is the flow-rate of water in the space and the smaller are the micro-bubbles.

In this case the diameter of the bubbles is, let us say 40-70μm. The depth of the flotation space is 2,5-3,5m and the depth of the tank is accordingly 3,0-4,0m. This means that the equal walls of the flotation space are shorter than the height of it. There is a thin stiff horizontal plate between the flotation space and the about 0,5m high bottom space of the tank. There are round orifices of different size all around the plate. The configuration of the plate with these orifices is the top secret part of this turbulent flotation application which has been protected by the Finnish, European and U. S. patents.

The role of this perforated plate is to control the flow of water in the flotation space and to distribute that evenly throughout the horizontal cross-section of that space, despite of the turbulent flow conditions there. When having seen this turbulent flotation working in a pilot-unit as well as in a full-scale unit, it seems to be completely clear that dissolved air flotation can be operated also in the turbulent flow conditions. The thickness or depth of the micro-bubble bed may be depending on the flow-rate 1,5-2,5m. It is also clear that this really deep-bed micro-bubble bed plays the major role both in the attaching of bubbles onto suspended solids and the removal of suspended solids from water.

The lower surface of the micro-bubble bed is completely horizontal which shows that the hydraulics of this turbulent flotation are controlled properly. The clarified water below the micro-bubble bed is very clear showing a very good removal efficiency of solids. The water to be treated by DAF is forced to flow evenly down through this micro-bubble bed which is regenerated

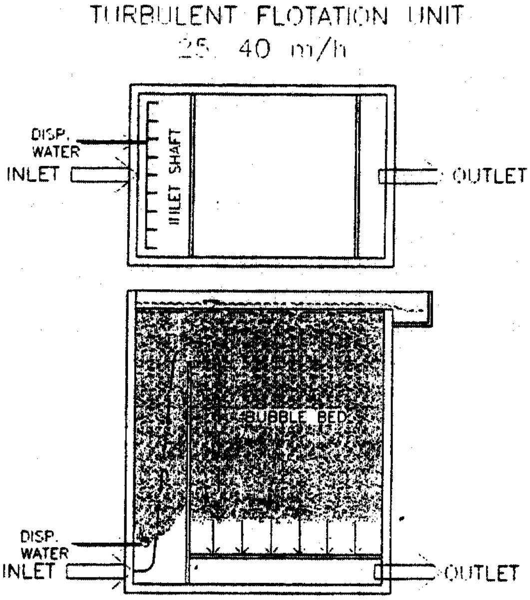

Fig. 4. A scheme of high flowrate DAF in Turbulent Flow Conditions

continuously. The turbulent flow of water can be seen easily, when looking at a pilot-unit having one transparent wall for observation of the flotation phenomenon

5. CONCLUSION: FURTHER DEVELOPMENT OF DAF-TECHNOLOGY

When considering the further development of DAF-technology taking in account that it is quite clear that dissolved air flotation can be operated as a controlled unit operation also in the turbulent flow conditions, the most interesting question is, how this clarification method of water treatment could be optimized? It seems to be clear that DAF's removal efficiency for suspended solids will not be reduced, when its hydraulic capacity — i.e. flow-rate — is increased. From this point of view it can be thought that the tank volume needed for dissolved air flotation could be further decreased by increasing the flow-rate of water.

From the practice it can be said that the limiting factor is the actual rising velocity of the micro-bubbles in the flotation space which is depending on the flow-rate of water. When this is increased in a constant DAF-unit, there will be at last a situation, when the bubbles have been driven to so a deep level in the unit that those start to escape from the unit with water being let out of it. in this way, the removal efficiency for suspended solids would be reduced rapidly.

The real rising velocity of the micro-bubbles in water flowing down vertically is depending on the size of those. There is always some specific size distribution of the micro-bubbles depending on the technical solution used for releasing dissolved air as bubbles or injection of air gas to the water to be treated by DAF. When we have an advanced dispersion equipment in use, the diameter of bubbles is always less than 100μm. This means that we are using bubbles which are really micro-bubbles. It is often told that the size distribution of bubbles is 40-70μm or even 40-60μm.

In theory, the optimization of DAF is a compromise between the flow-rate of water and the size of micro-bubbles. However in practice, if we decide that the minimum reasonable bubble size is 40-60μm. it seems to be clear that the maximum flow-rate of water will be 30-40m/h, when we do not want to have extra deep flotation tanks (more than 5m). In the laboratory conditions, we certainly can construct even deeper flotation units for flow-rates of water up to 60m/h or even higher than that and use smaller bubble size than 40μm, if those are seen worth of searching.

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