INDUCED GAS FLOTATION PROCESS FOR WATER CLARIFICATION

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ABSTRACT

Removal of emulsified oil from waste water is receiving renewed attention in light of best practical control technology and treatment level requirements. This paper presents a discussion of the induced-gas flotation process as a method for cleaning waste waters by removing suspended contaminants using froth floration. The origin of the process is briefly reviewed and a comparison is made to dissolved-air flotation showing that the two processes have both similarities and differences.

A method of inducing and dispersing gas bubbles into water with individual cell mechanisms is discussed. Consideration is given to both the hydraulic and chemical characteristics of the stream. The complete flotation machine incorporating multiple cells in series is assessed from the mechanical design standpoint. The operation of induced-gas flotation equipment is explained.

Consideration is given to the interrelationship of various design and operational aspects of this process. Both the importance and the limitation of chemical treatment additives are pointed out. A bench test method for selecting chemical treatment is discussed with a critical review of its ability to predict scale-up unit performance and the chemical formulation and volume requirements.

Review of past oilfield experience with induced gas flotation machinery shows that this is a viable method for cleaning produced water of suspended oil and solid particles.

HISTORY OF PROCESS

Induced or dispersed gas flotation had its origin in minerals benification during the early 1900's. Finely crushed ore was mixed with water and then passed through cells containing a rotating mechanism that generated and dispersed many small air bubbles. Oils were added as reagents that caused the mineral particles to be attracted to the small bubbles and floated to the cell surface. The bubbles concentrated mineral particles as a froth head that was skimmed off and collected in troughs along opposite sides of the cell. This dispersed or induced air flotation technique is the principal method used to concentrate copper, iron, lead, zinc, and phosphate. Thus, historically induced air flotation has been used in the dry minerals industry to remove dispersed particles from a water slurry. WEMCO Division did pioneer work in minerals flotation and has manufactured minerals industry machinery for many years. Tretolite and WEMCO devised a process using chemicals and an induced gas flotation machine to clean dispersed matter from water. This process was introduced into petroleum-production operations late in 1969 to clean oily produced water for reinjection.

Until that time, application of flotation techniques to water cleaning had been through dissolved air flotation units. This method dissolves air in water at increased pressure. When pressure is released in a cell containing water to be cleaned, the pressure drop causes small bubbles to be released. The bubbles float dispersed material to the surface for removal by skimming. The fundamental difference between "induced" and "dissolved" gas flotation is, therefore, the method by which air or gas is introduced into a water system. Induced gas flotation mechanically mixes a gaseous phase intimately with the liquid phase. Surface adherence between a gas bubble and an oil or solid particle then provides the basis for removal of this contaminate by floating it to the surface. The fundamental difference in the two methods provides several distinguishing features.

- The average gas-bubble size in a dissolved air flotation cell is considerably smaller than in an induced gas vessel. Therefore, the total gas flow for induced gas flotation must exceed that for dissolved air flotation.

- The kinetics of induced gas flotation is very rapid and results in a relatively short retention time which allows an accompanying reduction in vessel volume or size.
- The internal energy and shear turbulence level in the induced gas cell is very much greater than that in the dissolved gas cell. A properly designed induced gas cell does, however, provide a relatively quiescent region for flotation and froth removal near the cell surface.

HYDRAULIC AND CHEMICAL REQUIREMENTS

Some induced gas flotation machines have required that air or gas be supplied to the cell under pressure from a compressor or other source outside the cell. Others injest gas by the operation of a fluid-circulating impeller only. Because the physical and operational advantages of the self-aerating design better satisfy a desire for simplicity and minimum power requirement, we will discuss that type cell, which is shown schematically in Figure 1.

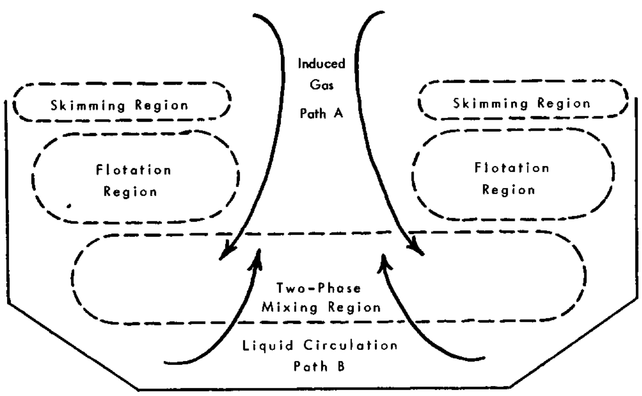

FIGURE 1—INDUCED GAS FLOTATION CELL HYDRAULIC CHARACTERISTICS.

There are two fluid flow paths — gas and liquid — and three distinct regions. Each of these regions is important in obtaining adequate contaminant-removal performance. The gas is naturally induced or self-induced and enters the liquid from the upper region or vapor space of the flotation vessel (path A). At the same time, liquid is circulated upward from the bottom region of the vessel (path B), meeting and mixing intimately with the gas in the two-phase mixing region. This region is of primary importance to the process. An adequate amount of gas must be induced and sufficiently sheared into finely dispersed bubbles in order to provide physical contact between the surface of an oil droplet or suspended solid particle and the surface of a gas bubble. Flotation is strongly influenced by the surface characteristics and interaction of the various phases. Several different mechanisms are involved in this sub-process including the following.

1. Collision between bubbles and suspended particles
2. Formation of contaminate flocs of multiple particles
3. Adsorption of bubbles onto the particles and floc structures

These mechanisms imply that chemical conditioning aspects of flotation are critical to process performance. Experience has proved this to be true. The surface chemistry affecting interaction of gas bubbles, water, and suspended particles in the induced-gas flotation process continues to receive considerable study.

In addition to the mixing region, an induced-gas flotation cell must provide a sufficiently quiescent flotation region through which contaminant gas bubbles can rise to separate the contaminant from the main body of water. Excessive disturbance in this region could cause separation of gas bubbles and contaminant or could cause reemulsification of contaminant particles into the water.

Also, the cell must provide a surface flow pattern that will allow sweeping the contaminant carrying froth from the cell (skimming region). The oil- and solid-laden froth or skim is produced as a result of partial bubble collapse at the surface. It should be removed from the cell continuously and with a minimum of mechanical disturbance.

Only a portion of total cell volume is used in the actual flotation and separation process. In the flotation region, effective density and size of the contaminant and bubble system must be such that rapid separation will occur. This required density and size is achieved in the mixing region. This implies that the size of oil droplets is sufficiently large and that high frequency of gas bubbles and oil droplet (or floc) contacts are provided. The induced-gas process usually generates bubbles which are larger than the original particle dispersion. The bubble and oil droplet or bubble and suspended solid interactions are governed by the system's surface chemistry. On contact, these surfaces must adhere rather than be repulsed. This surface characteristic is provided or enhanced by use of specific chemical conditioning agents. The metalic salt coagulants such as iron, aluminum, and calcium are generally less effective than organic-polymer flotation aids in the induced gas process. This is probably due to the polymer's ionic charge and its high molecular weight (long chain). The organic polyelectrolytes also provide a reduced sludge volume that is more readily treated for oil recovery than the inorganic coagulant sludge.

FLOTATION MACHINE DESIGN

The typical configuration for induced gas flotation machines is the arrangement of four active flotation cells in series as shown in Figure 2. Flow enters the machine through a feed box and leaves through a discharge compartment. The active cells, the feed, and the discharge compartments share common bulkheads. Each cell in the series operates independently. Flow enters and leaves each cell through an opening at the bottom of the connecting bulkheads. These bulkheads, or baffles, extend above the liquid level so that no flow occurs from cell to cell along the liquid surface near the top of the machine.

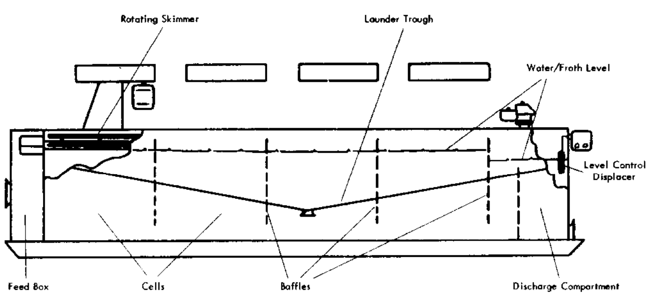

FIGURE 2—TYPICAL CONFIGURATION FOR INDUCED GAS FLOTATION MACHINE.

Rotating float or froth skimmer shafts are located along each side of the machine. Paddles in each cell are attached to the shaft and sweep or skim froth and floating contaminates over an adjustable weir and into a launder trough for removal from the machine.

The discharge compartment allows remaining gas bubbles and floatable oil particles to separate from the body of treated water. A displacer (sensor) for a liquid-level controller is located in this essentially unaerated compartment. In typical operation, a liquid-level control valve is located downstream from the machine to regulate effluent flow so as to maintain a constant level within the machine.

Provision is made for the machine to be sealed so that air (and its oxygen) may be excluded and the flotation process conducted under a gas blanket. If natural gas is made to flow through the sealed machine, dissolved oxygen can be stripped from the water and removed from the system.

The optimum number of flotation cells for a specific application may not always be the same. Feed contaminant concentration, effluent quality requirements, stability of dispersed matter, available space, and economics influence the optimization. It is evident that a single cell could experience underflow short circuit problems and that additional cells in series would progressively reduce short circuiting by approaching perfect mixing performance. Experimental tests have shown that short circuiting of the underflow is prevented with three cells in series. A fourth cell was considered an additional safety factor. Other tests have shown that the four cells in series produces "plug flow-through" in the practical sense. The four cell configuration with one minute per cell, or four minute overall retention time, has, in several hundred installations, provided the effluent water quality needed in a variety of systems.

The individual cell hydraulic requirements described in Figure 1 could be satisfied with various mechanisms. One design concept is shown in Figure 3. This is a partial section through one of the four active flotation cells identified in Figure 2. The major elements of this mechanism include a straight-vaned rotor suspended below a standpipe and surrounded by a disperser. Operation of the rotor generates a fluid vortex that extends internally up the side wall of the standpipe and down toward the rotor bottom. The natural result of this liquid vortex is a static pressure reduction in its central, non-liquid region. This reduced pressure region is made to communicate with either the ambient or with the sealed flotation machine free board or vapor space. As a consequence, a natural flow of air or gas is induced into the vortex core.

A second consequence of rotor operation is the generation of a circulating liquid flow up from the bottom of the machine to the rotor. This flow moves unaerated water toward the mixing region. This circulating flow also tends to prevent short-circuit flow.

The injested gas and circulating liquid mix intimately under the action of the rotor. Gas and liquid leave the rotor as a two-phase mixture with a tangential momentum direction. The disperser transforms this flow into the radial direction, as viewed along the rotor axis, by causing the two-phase fluid mixture to pass through a matrix of radial passages shown in Figure 3. This change in fluid momentum is accompanied by a significant shear turbulence that promotes increased gas and liquid mixing and reduction of gas-bubble size. In relating these actions to the schematic Figure 1, note that the gas-injestion path is downward from ambient or machine vapor space through the core of the vortex to the rotor while the liquid circulation path is upward from the bottom of the machine toward the rotor. The two-phase mixing region extends from the rotor outward beyond the disperser. With steady state mechanism operation, a two-phase fluid mixture is established in the upper half or two-thirds of the flotation cell. The stationary hood produces a quieter region above the rotor and disperser. This is the flotation region where the principal separation of contaminants and water occur. Gas bubbles and contaminant particles (or flocs) rise while cleaned water is recirculated back to the bottom of the machine. Depending on the flotation cell size, the water is circulated in this manner as many as eight times before leaving each cell in the machine.

As the gas and contaminant froth reach the surface, gas bubbles begin to collapse, further

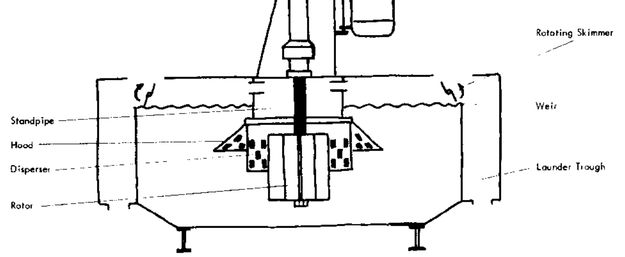

FIGURE 3—INDUCED GAS FLOTATION CELL AERATION MECHANISM.

concentrating the contaminants. The surface flow pattern is important to good contaminant removal performance because it is necessary to continuously remove this froth without either excessive turbulence or surface flow stagnation. The surface condition is effected by turbulence and by the amount and stability of the froth. The turbulence reduction requirement is satisfied by the hood. The froth requirement is provided by the natural chemistry of the water along with the chemical added to condition water for clarification. Two blade-skimmer paddles and an adjustable weir in each cell allow rather close control of the positive mechanical sweeping in the skimming action.

OPERATING CONSIDERATIONS

Under operating conditions, most waste water treatment systems including those used for oilfield produced waters, will experience fluctuations in influent waste load. The degree to which these fluctuations affect performance of the system depends on the "buffering capacity" of the overall plant design and the options available to the plant operator in handling fluctuations. Overall plant design should contain provision for preventing free oil from entering an induced gas flotation machine. This is usually accomplished with a skim tank or a vessel such as an API separator or a parallel plate inteceptor upstream from the flotation unit. A well operating free water knockout, gunbarrel, or emulsion treater will prevent free oil from reaching the flotation system. A skim tank immediately upstream from the flotation machine would provide further insurance against free-oil entry as well as provide surge capacity and averaging or equalization of influent flow. Sequential cell-to-cell reduction in contaminant concentration in the flotation machine affords a degree of safety in handling fluctuations in flow and influent contaminant concentration. An option available to the operator is polymer addition. It is generally used on a continuous basis, but amount or type can be controlled. It has been shown that although flotation aid chemicals enhance removal efficiency, they also can inhibit the process if added in too large a quantity. Selection of both the proper chemical and the correct injection rate is an important step in establishing a successful treating program.

BENCH TESTING

Proper chemical and injection rate are established using the results of tests run with a small batch test machine. It has a single mechanism that is a miniature version of the full-scale mechanisms. It is turned by a small electric motor. A three-liter sample of the water to be cleaned is placed in the test cell bowl that contains the small mechanism. A measured amount of test chemical is injected using a microliter syringe. (The usual treating range is from 5 to 20 ppm.) The mechanism is rotated for a precisely timed interval. Oily froth that floats is removed from the surface by skimming or brushing it over the edge of the bowl. Effectiveness of a chemical is judged by comparing oil (contaminant) level of the sample before and after the test run. Oil in water can be measured by extracting oil from a known volume of water with solvent, then measuring the oil by gravimetric, infra-red absorbance, or photometric means. Turbidity comparisons of water samples is often used in tests used to screen many chemical formulations that may be effective. When the best reagent has been selected, it is normally possible to predict with reasonable accuracy both the injection ratio required and the effectiveness that can be expected from the scale-up or full stream commercial size flotation unit. Some field experience may be required to obtain this correlation between the batch test unit and the fullsize unit which has dynamic flow. Ordinarily, the batch test sample is aerated for only one to two minutes to give correlation with the dynamic machine's 4-minute retention time at rated capacity. The bench test has been used successfully for selecting chemical and dosage as well as for predicting performance of full-size induced gas-flotation machines.

OILFIELD USE

Induced-gas flotation represents a viable alternative to conventional dissolved-gas flotation for many industrial waste water applications including oilfield produced water clarification. Between 550 and 600 induced gas-flotation units have been put into water clarifying service thus far in the 1970's. Most of these are in petroleum industry service. Some 500 machines are in service clarifying produced water for the following uses.

1. waterflooding
2. steam generator feed
3. disposal
   a. surface streams
   b. offshore waters
   c. subsurface formations

In some installations, the induced-gas flotation process is the final clarification treatment. In other cases, it is followed by filtration, ion exchange softening, or biological treatment. Almost universally, induced gas flotation will reduce produced water-oil counts to less than 30 ppm of oil remaining. In many areas, oil count is reduced to below 10 ppm oil. When filtration is required, water must be free of all but very low levels of oil and suspended solids if filtration is to be effective and economical. Filtration is, therefore, best used as a polishing method and induced-gas flotation is often useful in clarifying water in preparation as filter feed. Ion exchange softners have no tolerance for oil, so produced water should go through flotation and filtration before being fed into a softner.

The induced-gas flotation concept for clarifying oily waters is finding increased application. It is a relatively high response flotation system that requires comparatively short liquid retention time. Gas flow is much higher than that in dissolved gas flotation. The increased gas flow is provided with a modest power input. Induced gas flotation is an effective and economical process for removing contaminates from wastewater streams.

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