DESIGN AND OPERATION OF A HYDROELECTRIC PLANT OIL-WATER SEPARATOR REFITTED WITH HIGH-EFFICIENCY SEPARATION MEDIA

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ABSTRACT

The Chelan Public Utilities District (PUD) facility at Rock Island dam was provided with two identical oil-water separators for treating wastewater in 1992. They were provided with a type of media that was originally designed for sanitary sewer plant trickling filters and is not optimized for oil water separation. In 2011, the PUD installed new high-efficiency oil-water separator media in one of the separators.

This paper will describe the engineering process used to determine the amount and configuration of media ideal for the separator, modifications to the media holding device to accommodate the new media, and installation of the new media.

The media has been in service for more than a year and the paper will also describe the results of operation of the separator with the new media in contrast with the identical separator operating with the old media. The retrofit was easy and has proved to be very successful. Oil removal with the new media is much better as evidenced by the much greater amount of oil captured by the separator with the new media versus the separator with the old media.

Keywords: Oil, water, oil-water separator, design, new media, performance, comparison

INTRODUCTION

The Rock Island Project was the first dam to span the Columbia River, with construction beginning in 1930 and completing in 1932. The Dam is located about 12 miles downstream from the city of Wenatchee. Two additional major expansions of the facility have been conducted since the original installation. Powerhouse 1 has eleven vertical shaft turbine generators and Powerhouse 2 has eight horizontal shaft hydraulic turbines. The total nameplate rating of both powerhouses at the dam is 623,725 kilowatts.

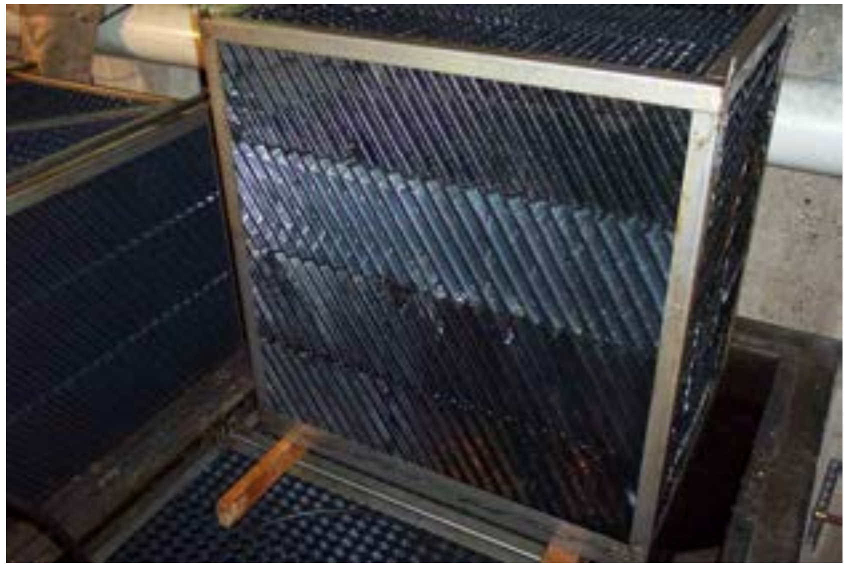
Rock Island Dam

Horizontal Shaft Hydraulic Turbine

In 1991, two large oil-water separators were installed to remove any oil that might leak from the equipment into the plant drainage water system. They were designed to treat the miscellaneous leakage water from the dam, mostly from the turbine pit. These separators operate in parallel.

Over the years, numerous problems were encountered in the use of these separators, mostly because of the design of the media and downstream dense pack. The media and dense pack became plugged and the “logs” of media installed were fragile and difficult to clean. The separation efficiency was not as good as was desired. The result of these problems was a necessity for substantially more maintenance time and expense than desired. Each separator contains four frames full of media plus a downstream dense pack, and they all had to be removed and cleaned with a portion of the media replaced at each instance. It was desired to reduce the annual maintenance time and costs.

Inlet End View of One Separator



Logs of Media Installed in One of the Frames

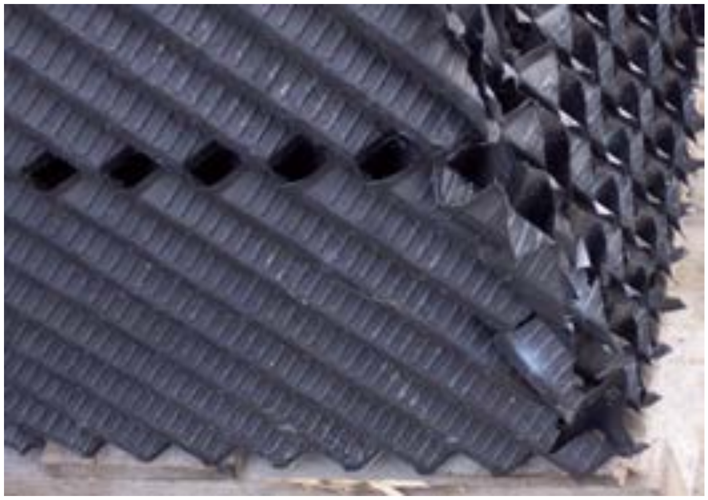
The installation has two of these separator units to treat the drainage water from the powerhouse. Flows can be as high as 600 US GPM to be equally shared by the units (i.e. max. 300 US GPM per unit). The system is fed by two screw centrifugal pumps that are located 100 ft below the separators. Typically, one pump is running and the other pump cycles on and off based on levels in the sump. Units will normally have a flow of at least 150 US GPM per unit (singe pump output is 300 US GPM that is run in parallel through the units). Plant leakage is rarely under 300 US GPM and is often higher. When the second pump starts, the output is 550 US GPM. There are isolation valves on the input to each separator and one is partially closed to balance the flow to both units.

The drainage water will typically have 10 to 30 ppm of oil in the water, but in the event of a spill within the powerhouse, this concentration can be much greater. The oil has a SG of 0.87 at 60 °F. The water is basically river water that has leaked into the powerhouse and will range in temperature from 2 °C to 20 °C. A daily turbidity test is logged using a Secchi disk. These numbers indicate a worst case of 8-ft clarity and an average of 15-ft clarity.

The plant has traditionally used a media that is a plastic corrugated bundle of 12 in x 12in x 48 inch, stacked to fit the frames. These bundles tend to clog easily, are difficult to clean and easy to break. This media was originally designed for use in trickling filters in sewage treatment plants and is not optimized for oil-water separation. It is very thin corrugated PVC plate welded together so that there are alternating cross channels.

In addition to the media, a foam mesh pad is installed downstream of the media. The mesh pads tend to plug with biological growth and accumulated oil, and when that happens, the water level rises about 2” over the pack and the top of the mesh pad. When this happens, much of the flow is not treated.

The units have experienced a greenish-gray growth that resembles the algae in the river. It is likely that the biological growth problems are due to poor oil removal leaving a great deal of oil that provides food for the microbes and it is also likely that some of the plant's biological problems occur because that type of media was designed to encourage bacterial growth and is virtually uncleanable.



Close-up View of Old Media, New Uninstalled

GENERAL DISCUSSION AND THEORY OF OIL-WATER SEPARATION

In 1845, an English mathematician named George Stokes first described the physical relationship that governs the settling solid particles in a liquid (Perry). This same relationship also governs the rising of light liquid droplets within a different, heavier liquid. This function, simply stated is:

$$Vp = \frac{G}{(18x\mu)} x(d_p - d_c) x D^2$$

Where:

V_p = particle rising or settling velocity, cm/sec
G = gravitational constant, 980 cm/sec^2
μ = absolute viscosity of continuous fluid, poise
d_p = density of particle (or droplet), gm/cm^2
d_c = density of continuous fluid, gm/cm^2
D = diameter of particle, cm

A negative velocity is referred to as the particle (or droplet) rise velocity.

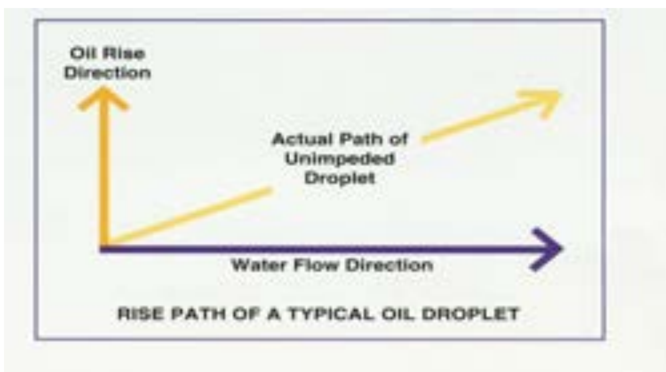
Assumptions Stokes made in this calculation are:

1) Particles are spherical
2) Particles are the same size
3) Flow is laminar, both horizontally and vertically. Laminar flow in this context means flowing gently, smoothly, and without turbulence.

From the above it may be seen that the variables are the viscosity of the continuous liquid, specific gravity difference between the continuous liquid and the particle, and the particle size.

The rise rate of oil droplets is also governed by Stokes's Law. If the droplet size, specific gravity, and viscosity of the continuous liquid are known, the rise rate may be calculated.

To calculate the size of an empty vessel gravity separator, it is first necessary to calculate, by the use of Stokes's Law, the rise velocity of the oil droplets. The size of the separator is then calculated by considering the path of a droplet entering at the bottom of one end of the separator and exiting from the other end of the separator. Sufficient volume (residence time) must be provided in the separator so that an oil droplet entering the separator at the bottom of the inlet end of the separator has time to rise to the surface, before the water carrying the droplet exits the opposite end of the separator.



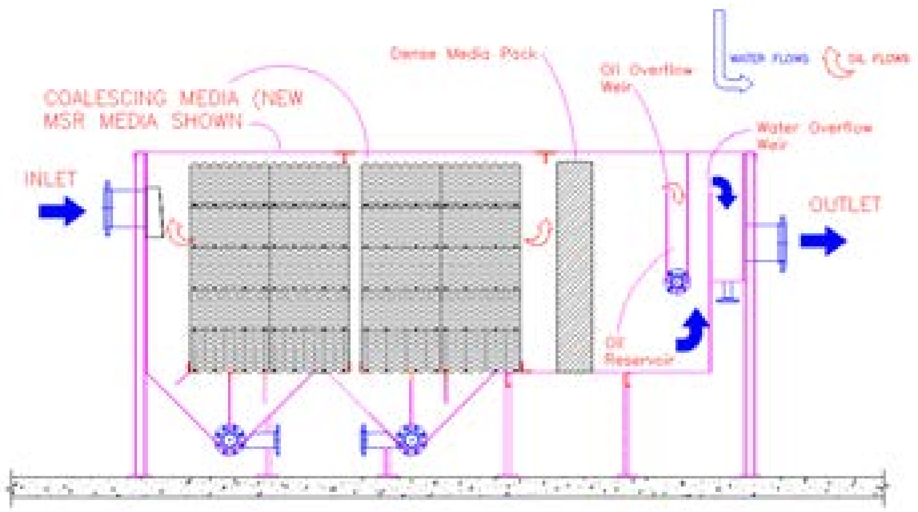
Calculation of rise rate by this method is a gross simplification of actual field conditions because oil droplets are not all the same size, and they tend to coalesce into larger droplets. Furthermore, inevitable turbulence within a separator makes an orderly rise of very small droplets impossible.

Droplets will rise following Stokes's Law so long as laminar flow conditions prevail. When the particle size exceeds that which causes a rise rate greater than the velocity of laminar flow, flow around them, as they rise, begins to be turbulent. Particles of this size and larger do not rise as rapidly as would be expected from calculations based on Stokes's Law because of the hydrodynamic drag. They do, however, rise very quickly in relationship to smaller droplets, and so are removed by a properly designed separator.

Very small particles, such as those of 8 microns (micrometers) and less in diameter, do not rise according to Stokes's Law (or hardly at all) because the random motion of the molecules of the water is sufficient to overcome the force of gravity, and therefore, they move in random directions. This random motion is known as Brownian Motion. Fortunately, the volume of a droplet decreases according to the cube of the diameter, so these very small droplets tend to contain very little oil by volume, and unless there are large, large quantities of very small droplets (such as would be created by using a centrifugal pump to pump the water) they contain negligible amounts of oil.

When the droplets coalesce, they do not form flocs as the solid particles can, but coalesce into larger droplets. Interfacial tension (sometimes referred to as surface tension) of the liquid tends to make the droplets assume spherical shapes, since this is the smallest possible shape for a given mass. This is convenient for a separator designer because it is required by Stokes's Law.

PROCESS REDESIGN OF THE SEPARATOR SYSTEMS



Separator Flow Schematic

The sketch above is a side view of the separator showing the frames with media and overflow system. Flow, as indicated on the drawing, is from left to right. The media within the system is contained in four frames. These are mounted in two rows of two frames. Downstream of the frames, a dense media (foam pad) polishing system is provided.

Dense Media Pack

Dense Media Pack Detail

Because the separators were already existing, and there are already stainless frames holding the coalescing media, it was planned to use as much of the existing equipment in place as possible.

Design conditions for the separators in the current operations are:

- Maximum flow of 300 US GPM each
- Minimum temperature of 36 °F
- Inlet oil content 100 mg per liter
- Average droplet size of 72 μm, which is consistent with the oil content and gently pumped flow
- Oil specific gravity of 0.87

Process calculations were performed utilizing the general configuration of the existing tank in frames and with two different media configurations (plate spacing of 8 mm and an alternate plate spacing of 16 mm). The 8mm spacing used only two of the original frames and eliminated the need for the two downstream frames. The 16 mm spacing used the same quantity of media but utilized all four frames.

The process calculations show that it was possible to achieve less than 10 mg per liter with either configuration, and because the cost was about the same, it was chosen to utilize the 16mm spacing because it is somewhat more solids tolerant. The expected effluent was less than nine mg per liter. This performance can be achieved without the use of the dense media pack, which caused some problems in the previous configuration.

The only revisions to the frames that were necessary were providing seal plates along the sides, to ensure all of the flow passes through the media, and additional supports under the media. The installation also required sealing of the frames to the side walls of the tank. The original configuration allowed large gaps between tank side walls and the frames. This allowed a certain percentage of the flow to short circuit the filter packs.

Redesigned Pack Bottom Supports

Lowering Pack into Separator

To install the new media, it was first necessary to remove the frames from the separator and then to remove the old media from the frames. New supports were added, as shown in the photo above, and also side seal plates of white polypropylene. The side seals can be seen in the photo above at the right.

Startup

Startup of the system was the same simple procedure as previous startups:

- Ensure the media and seals are correctly installed
- Check weirs and adjust as necessary
- Start flow to system

Operations

The two separators started out with brand new media and an all clean system. One separator had the high efficiency media, the other was filled with the old original media. The supply is evenly shared between the two systems. After a year, there was a startling difference in the amount of oil collected between the two separators.

Grab samples taken after several months of operation indicate that there was very little oil in the incoming water and everything was clean. The analysis method used was EPA 1664, which is a hexane extraction/infrared spectrophotometry. There was not a large difference noted between inlet and outlet water oil contents, but this is likely due to the very small droplet size distribution expected because of the very small inlet concentration.

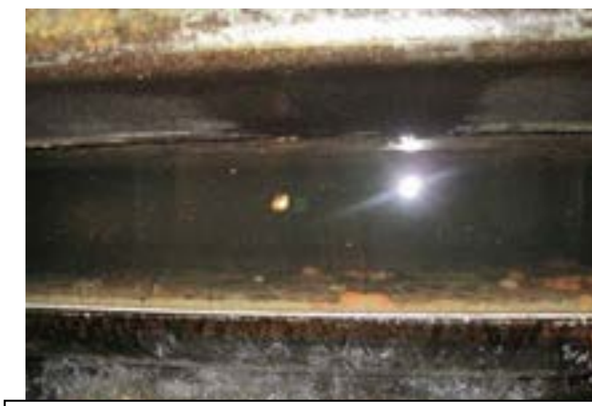
After more than one year of operation, the new high-efficiency media installed in the separator has been shown to be much more efficient than the previous media by comparison of the captured oil and bacterial growth. The photos below illustrate the difference in operations of the separators with the old media and the new high-efficiency media.

Separator with Old Media and Little Oil Collected on Top of Water

Separator with New Media and Large Quantities of Oil Collected

In the old media photo, it is difficult to see the collected oil, but in the new media separator, large quantities of oil can be seen clearly.

Old Media Separator Water Overflow with Substantial Bacterial Growth



New Media Separator Water Overflow with Little or No Bacterial Growth

The gray fringes on the water overflow weir photo, shown at left above, indicate substantial bacterial growth. The bacteria use the oil as a food source (Green and Trett), so when the oil is not removed almost completely, some of the oil will pass into the downstream end of the separator and bacterial growth will occur there.

The water overflow weir in the photo at right is from the separator with the high-efficiency media. The absence of bacterial growth in this system indicates that the oil has almost completely been removed to the top of the water level, where it cannot be readily accessed by the bacteria for food.

There is a remarkable difference in operations between the two separators with different media. After one year of head to head service, the original media has managed to collect a small sheen in the oil collection chamber, whereas the MSR high-efficiency media has a thick layer of oil that is clean with little biology growing in or on it. It would appear that this oil has collected to a level that is actually overflowing into the oil pocket and oil is being removed. This has not been seen in the ten years that the author has tried to fix the system. It is now worthwhile to put in a proper skimmer.

Above is an example of the old media after one year's operation. The amount of growth and solids collected here was an operational problem, which was further compounded by the downstream foam packs. These tended to clog and cause more solids to plug the media and the water to overtop all of the separation media.

Further, the overall growth of algae is drastically different. The old media is covered and packed with growth, and the MSR media looks very clean. This is because the new media is optimized for oil-water separation, whereas the previous media was designed to promote bacterial growth in trickling filters.

SUMMARY AND CONCLUSIONS

The MSR high-efficiency media is making a large difference in the operation of the separator. It is removing much more oil than the previous design media. Furthermore, bacterial growth is almost eliminated, thereby making maintenance easier, quicker, and less expensive. The operations of the separator are much more efficient and this will reduce the amount of oil that is allowed to escape into the environment.

At the earliest possible opportunity, the old style media in the separator, which was not previously refitted, will be changed. Regular maintenance will be performed and the system process performance will continue to be monitored in order to ensure that good separation continues.

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