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Wastewater

By Charri Lou Garber

The total amount of water on Earth is fixed. The water available today is the same amount that was available five billion years ago, when the Earth was first formed. Every drop of water we use for washing, cooking, or drinking has been used countless times before. It is estimated that a drop of water from the source of the Mississippi River will be used *17 times* before it reaches the Gulf of Mexico. There are efficient, modern methods for purifying wastewater, and it's my job to keep one wastewater treatment plant operating smoothly.

Sewage—the very sound of the word turns my stomach and wrinkles my nose. I like the term wastewater because it defines what sewage really is. Wastewater is the water that flows down the drain of your sink, shower, and toilet. In towns and cities, it's collected by sewer pipes and transported to a wastewater treatment plant like mine. What's in wastewater? To find out what it is, and what happens to it, imagine you're a soap bubble floating in the bathtub.

Whoosh

Suddenly the plug is pulled, and you're whirled down the drain. Once inside your house's drain pipe, you flow along to the street into a larger pipe. Here you're mixed with more wastewater from surrounding houses. Now you float along with material that is in solution (such as pancake syrup, urine); material that is colloidal (such as used dishwashing detergent); and solids that are temporarily suspended only because the water moves quickly, such as coffee grounds, lettuce leaves, feces (broken up and unrecognizable), toilet paper, and even the occasional sock from the laundromat down the street.

You flow along (remember, you're the charming bubble, not that other disgusting stuff) at a speed of about 0.6 meters per second—fast enough to keep everything movng along. The water gets deeper and soon you pour into a larger pipe. Here you're mixed with more stuff: waste chemicals from a photo finishing business, plastic gloves. You name it, it's there.

It begins to rain, and, if you're in one of those cities that has just one network of pipes, water pours in from the storm drains. The water gets deeper and flows much faster. Rainwater isn't the only thing flowing in, though. There's dirt from the road, leaves and twigs from the trees, spilled gasoline and oil from service stations, and even gum wrappers and soda cans.

The water starts to slow down as you near a hill. To get over the hill you enter a lift station where large pumps lift you to a higher elevation. You continue your downhill flow. At last you see the light at the end of the tunnel. You've made it to the treatment plant.

The wastewater flows through a Parshall Flume, which measures the quantity of water and tells the plant operators how many millions of gallons of wastewater they have to treat. Now the process of separating wastewater into waste and water begins.

Primary treatment

The first part, called primary treatment, is a simple physical process. The wastewater first flows through a bar screen (Step 1 in illustration), a set of vertical bars that catch the larger stuff—rags, twigs, plastic bottles, and the occasional dollar bill. The bar screen is raked periodically and the debris hauled to a landfill (after it's been checked for dollar bills).

If the wastewater has been in the sewer pipes a long time, decomposition has started. Because this is the first place the water has been exposed to the air, hydrogen sulfide (H_2S, from decomposition of proteins) is released, and its characteristic odor—rotten eggs—is present. Chlorine can be added to the waste water to control the odor because Cl_2 oxidizes H_2S.

$$H_2S + 4Cl_2 + 4H_2O \Rightarrow 8Cl^- + SO_4^{2-} + 10H^+$$

The water then flows into a long, narrow, knee-deep channel called a grit chamber (Step 2). Here the water is slowed to about 0.3 meter per second which allows what we call grit—the sand, rocks, coffee grounds, and diamond rings—to settle. The grit is periodically removed and hauled to a landfill. The stream should now be free of inorganic material.

The flow rate is still fast enough to keep the lettuce leaves, corn, and toilet paper moving. These are organic solids and can create a nuisance if not treated properly, so the next step in the wastewater treatment process removes the organic material that is either lighter or heavier than water. The water flows into a primary clarifier (Step 3), a large, circular, cement pond about three meters deep. The wastewater enters at the center of the clarifier and flows toward the edge. The lighter organic solids and scum float to the top of the tank. The heavier organic material—called sludge—sinks to the bottom.

Along the outer edge of the tank is a plastic (polyvinylchloride) barrier that has a series of W's cut from its top edge, forming a weir. The weir lets water flow out faster when the water level in the tank is higher, and slower when the level is lower. Thus the weir maintains a constant water level. At this point, the primary clarifier has separated the main water stream from the "floaters" and the "sinkers."

This is the end of the primary treatment, and 30% of the "pollution" has been removed. The main water stream continues to the next stage, carrying materials that are dissolved (sugar, etc.) and colloidal (very small particles). Secondary treatment turns these materials into larger solids that can settle out and be removed.

Secondary treatment

Secondary treatment is a biological process that relies on microscopic "bugs" to decompose the organic wastes. The action takes place in a deep, rectangular tank known as an aeration basin (Step 4). At the bottom, a series of pipes with small holes releases air into the tank. The churning action reminds me of blowing air through a straw into a glass of chocolate milk. At the head of the tank, microbe-rich sludge (obtained from one of the later stages) is added. This material is called RAS (return activated sludge) and is a brown mass, teeming with hungry bacteria, fungi, and protozoa.

Give these actors air, water, agitation, and some time, and they will feed on the waste, grow, and reproduce. These microorganisms contain all the building blocks of life: complex carbohydrates, proteins, nucleic acids, and lipids. As they consume the organic waste, the microorganisms grow and reproduce, forming a larger biomass. About 30% of the organic waste is converted into biomass, and 70% is oxidized into CO_2 and H_2O.

Urea, the primary compound in urine, and other organic nitrogen compounds are degraded to form ammonia.

$$\underset{\text{urea}}{(NH_2)_2CO} + H_2O \Rightarrow CO_2 + \underset{\text{ammonia}}{2NH_3}$$

Much of the ammonia is "fixed" into proteins and nucleic acids by the growing biomass. Excess ammonia can be oxidized by certain bacteria to form nitrites.

$$2NH_3 + 3O_2 \Rightarrow 2NO_2 + 2H_2O\ 2H^+$$

Different organisms can then oxidize the nitrites to nitrates.

$$2NO_2^- + O_2 \Rightarrow 2NO_3^-$$

These two transformations are called nitrification. The treatment process has now removed 85% to 95% of the "pollution."

This chocolate-colored mass then leaves the tank and flows into a secondary clarifier (Step 5). It is deeper and larger than the primary clarifier because activated sludge particles are finer than raw sludge particles and need more time to settle. Here again, what will settle, settles. This settled sludge is called activated sludge because it contains active microbes. Some of it is taken out of the system and treated further. The rest is returned to the aeration basin as RAS.

Looks great, but...

The water that flows over the weir of the secondary clarifier is clear and sparkling. To the naked eye it looks pure and safe to drink, but it can contain pathogens—harmful bacteria, viruses, and protozoa. Some pathogens can cause typhoid, cholera, and dysentery, so the water must be disinfected. This is done in the chlorine contact basin (Step 6), which is long, narrow, deep, and shaped like a maze.

Chlorine gas, Cl_2, a powerful oxidizing agent, flows from a storage cylinder, is mixed with water to form a solution, and is injected into the treated wastewater at the head of the disinfection basin. When Cl_2 gas is dissolved in water, it undergoes a series of pH-sensitive equilibrium reactions. At a neutral pH, both the hypochlorite ion and hypochlorous acid are present, and both can kill pathogens.

Molecular Chlorine		Chloride ion		Hypochlorous acid
$Cl_2 + H_2O$	$\Leftrightarrow$	$H^+ + Cl^-$	+	HOCL

		Hypochlorite ion
HOCL	$\Leftrightarrow$	$H^+ + OCl^-$

As the wastewater flows through the basin, some of the bacteria and viruses are killed, depending on the concentration of hypochlorous acid and hypochlorite ion. If sufficient chlorine has been added, any and all bacteria will be killed, so a proper dosage must be maintained. This is accomplished through sampling and testing.

The disinfected wastewater then leaves the plant and is discharged into a nearby river, lake, or ocean (Step 7). Properly treated wastewater will have no detrimental effect on the receiving water.

We've made the main water stream safe, but we still must treat all that sludge that settled to the bottom.

Going DAFT

In secondary treatment, sludge settled in the secondary clarifier (Step 5). This sludge is thin and smooth. It contains only 1% pollutants, but these fine particles are difficult to separate from the water. Our goal now is to make the tiny solid particles clump together so they can be removed. This requires the chemical action of a coagulant and the physical action of air bubbles. First, some iron(III) chloride is added, and it reacts with the hydroxide present in the alkaline water.

$$FeCl_3(aq) + 3OH^- \Rightarrow Fe(OH)_3(s) + 3Cl^-(aq)$$

The resulting precipitate, $Fe(OH)_3$, is fluffy and porous (flocculent) and physically entraps the tiny sludge particles. (Alum may be used instead, and lime may be needed to supply the alkalinity; some plants substitute an organic polymer.) The stream now flows into the Dissolved Air Flotation Thickener (DAFT), which is a deep, rectangular, concrete basin (Step 8). Water and air are mixed to make a foam that floats the sludge to the top of the tank. A portion of the water is recycled through a pressurized tank where compressed air is introduced. Under a pressure of five atmospheres, more air than usual dissolves in the water (an example of Henry's Law); when the water returns to the DAFT basin and atmospheric pressure, bubbles come flooding out of the water, forcing the flocculent precipitate and its trapped sludge particles to the surface. Another barrier holds the floating waste in place while the liquid stream flows on.

The surface of the DAFT basin now resembles dark brown cottage cheese. It is coated with sludge that is now 4% solids. These solids are skimmed and pumped to the digester.

The digester

To me, a digester (Step 9) is like a man-made stomach. It is an airtight tank where anaerobic microorganisms consume organic material (raw sludge, scum). The end product is a stable, black liquid that can be disposed of without causing odors or creating a nuisance. To speed up the process, the digester is heated to 37 °C (98 °F), the optimum temperature for methane-producing bacteria.

Where do we get the heat to keep the digester warm? One of the digester byproducts is methane gas, CH_4 (the compound in the natural gas that you may use to fuel your kitchen stove). The methane is burned under boilers; the hot water is used to heat the digester. Raw sludge is fed continuously, and the process takes about 20 days. When it's all over, the treated sludge can be applied to land as a fertilizer (Step 10).

The sludge digestion process is actually done by two groups of bacteria. The first digests organic compounds into organic acids, causing the pH to drop as low as 4.8. The acids formed are then consumed by a second group of bacteria called methane formers. The methane formers feed on the organic acids and produce digester gas, a mixture of CH_4, CO_2, H_2S, and H_2O. Without the methane formers to consume the acids, the pH would soon be too low to effectively operate the digester. The methane formers are very sensitive to pH and temperature. Both groups of bacteria are growing at the same time and in the same place, and the process must be monitored through laboratory tests. A healthy digester has a pH of 7.0 (neutral).

Upset stomach?

The digester is huge, but it is closed and sealed. I can't see through its solid concrete walls (like Superman!). How can I tell whether it is healthy? I rely on a set of chemical tests to see what's happening on the other side of the wall. I measure pH, alkalinity, and volatile fatty acid content to keep my digester in control.

Many chemical tests help me purify your wastewater. I know how much Cl_2 to inject by calculating chlorine demand, then confirming that it was sufficient to do the job by testing for the presence of fecal coliform bacteria. How do I know if a toxic industrial contaminant is present? By running a BOD (biochemical oxygen demand) or COD (chemical oxygen demand) test. How much nitrogen is in there? I'll run the TKN (total Kjeldahl nitrogen) test. Heavy metals? I'll use atomic absorption spectroscopy.

That's why I don't turn up my nose when someone says wastewater. To me, wastewater doesn't represent smelly sewage; it represents a great opportunity to run a chemistry lab, operate a major processing plant, and help other people by keeping their water clean and taking care of their waste. Keep it coming!

BIOGRAPHY

Charri Lou Garber is the lead operator at a 29-mgd (million gallons per day) water pollution control facility in Bremerton, WA. She entered the water treatment field through the C.E.T.A. program in 1979 and was trained both in the classroom and on the job.

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