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- A Brief Introduction to Centrifugal
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- Water by Adsorptive Media
- Removal of Asbestos from Drinking
  Problems
- Health Effects of Premise Plumbing
- Point of Use: The Final Barrier
Introduction

WQA proudly offers another member-exclusive educational kit, to help you stay current on water quality trends and keep up your technical knowledge.

The first two articles – John McEncroe’s “Point of Use: The Final Barrier” and Dr. Marc Edwards’s “Health Effects of Premise Plumbing Problems” – underscore the need for final barrier protection of drinking water at the point-of-use. The articles review potentially dangerous conditions both in the main distribution system and in-home plumbing that can degrade water quality.

An excerpt from a USEPA design manual for the treatment of arsenic-containing contaminants, “Arsenic Removal with Adsorptive Media,” discusses the various arsenic compounds in water and the available regenerative and nonregenerative treatment media. This offers excellent background for an upcoming presentation at WQA Aquatech USA 2011 from Thomas Sorg, PE, of the USEPA on a pilot study of arsenic treatment for a small system that compares disposable and regenerative media.

Finally, Dr. Joe Evans’s “A Brief Intro to Centrifugal Pumps” provides a tutorial on the workings of centrifugal pumps and understanding pump curves.

Test your understanding of these articles with the included quizzes. WQA-certified personnel can earn up to 1.0 CPD credits toward their recertification by earning a grade of 70% correct or higher on all quizzes. Quizzes may be taken online for instant feedback. See the answer sheet for the link.

Sincerely,

Tanya Lubner, PhD
Director of Education & Certification
Water Quality Association

Additional education resources can be found organized by topic wqa.org/education, and are available in the WQA Store at wqa.org/store or by calling 630 505 0160.

Each year, WQA Aquatech USA offers nearly 30 consecutive hours of education on a wide variety of water treatment topics. See wqa-aquatech.com for the upcoming 2011 sessions. Recordings and speaker slides from past meetings are available through the WQA Store (wqa.org/store, 630 505 0160).
In the past, drinking water utilities focused their treatment efforts at the plant, implementing chlorination, filtration, coagulation/sedimentation, and other processes. Because of growing concerns about water quality integrity, the multiple-barrier approach to water treatment became even more important. The multiple-barrier approach consists of maintaining a protected source, adequate treatment, and proper design and operation of the distribution system.

If all of these approaches are not successful in removing contaminants from water, utilities do have options. These options include:

- investing in complex and/or expensive centralized treatment processes,
- promoting the use of bottled water, or
- embracing a paradigm shift to point-of-use (POU) devices (Siegrist, 2004).

This article focuses on problems that can occur within the distribution system and the POU devices that can be used to address these problems.

**CAUSES OF DISTRIBUTION SYSTEM DEGRADATION**

As drinking water flows through the distribution system from the treatment plant to the consumer's tap, its aesthetic, microbial, and chemical qualities may deteriorate significantly (Baribeau, 2001). Increases in bacterial counts, decreases in disinfectant residuals, or changes in taste and odor characteristics are often related to distance from the treatment plant or increase in water residence time. Causes of contamination include formation of disinfection byproducts (DBPs), distribution systems repairs and replacement, hydraulic surges, power outages, fire flow, and backpressure.

**DBPs.** Traditionally, a residual concentration of chlorine – the most commonly disinfectant – is used to limit bacterial growth or regrowth in the distribution system. However, chlorine dose must be limited because it reacts with organic matter to form halogenated DBPs, some of which are of concern because of potential health risks (USEPA, 1994; NCI, 1976). Treatment processes, disinfecting conditions at treatment plants, and varying distribution system characteristics influence the residual disinfectant stability as well as DBP formation or decay.

**Repairs and replacement.** Distribution systems can be quite complex. Once water leaves the treatment facility, it may flow through many miles of piping that are subject to contamination intrusion or backflow/backpressure. “Because distribution systems are buried over large areas, the intrusion risk from structural deficiencies will never be completely overcome and can only be managed through rigorous maintenance programs including inspection, repair, and replacement” (Lindley & Buchberger, 2002). Depending on the circumstances, a distribution contamination event may overpower the residual disinfectant and result in a serious disease outbreak.

**Power outages and leaks.** When electrical power is lost, even for a brief period of time, unavoidable pressure drops and transient pressure surges occur in the distribution system. Without the power supplied from the pump, the water column may separate, resulting in pressure surges or negative pressure. If the distribution system piping were leakproof, these episodes would likely disrupt any biofilms and/or tubercles present within the pipe but would not expose the system to contamination from external sources. However, water system piping is not leakproof. “It is not uncommon for water systems to lose more than 10 percent of the total water production through leaks in the pipelines” (LeChevallier et al, 2002).

**Cross connections and backflow/backpressure.** Although numerous devices, including air gaps, vacuum breakers, check valves, and reduced-pressure backflow preventers, are used to ensure that nonpotable water and/or chemicals from manufacturing processes do not contaminate the potable water systems, contamination still occurs. Craun and Calderon noted in a USEPA White Paper (2002a) that “30.3 percent of waterborne disease outbreaks in community water systems during 1971-1998 were caused by contamination of water in the distribution systems. Of these waterborne disease outbreaks caused by distribution system deficiencies, 50.6 percent were due to cross-connection and backflow.”

**Biofilms.** Many different microbes are able to survive in the distribution system; some even possess the ability to grow and/or produce biofilms. Some of these organisms may be primary pathogens (i.e., those that cause disease in healthy individuals), whereas others may be opportunistic pathogens (i.e., those that cause disease in individuals with underlying conditions that may facilitate infection). These microbes enter distribution systems through a wide range of avenues, including treatment processes and deficiencies of the distribution system infrastructure. “Once biofilm development begins, subsequent material, organisms, and contamination introduced to the distribution system can become entrained in the biofilm. The biofilm can protect microbes from disinfection and allow microbes injured by environmental stress and disinfectants to recover and grow” (USEPA, 2002b).
Emerging conditions. Emerging contaminants that are of concern to water utilities today include compounds on the Contaminant Candidate List (CCL), endocrine-disrupting compounds (EDCs), personal care products, and pharmaceutically active compounds. Although these contaminants can be removed by centralized treatment (at considerable expense), this treatment does not address the existing concerns presented by distribution system vulnerabilities.

Until recently, analytical instruments were not sensitive enough to accurately measure EDCs at the levels typically found in the environment. “In addition to concerns about individual EDCs, there is concern about the cocktail effect of numerous micropollutants and/or their metabolites” (Drewes, 2004).

“Recent studies in countries all over the world have documented the presence of a wide variety of substances contained in pharmaceuticals and personal care products in the environment. PCPs (personal care products) and human PhACs (pharmaceutically active compounds) enter the water system largely from municipal sewage, and veterinary PhACs in the water system result mainly from agricultural waste. Concerns have been raised as to the impact of PhACs on aquatic organisms and on human health should the PhACs reach drinking water… The issue of PhACs and PCPs and their residues is part of the research agenda of most of the Global [Water] Research Council members and is on the priority list of [the] GWRC” (Palsma et al, 2003).

BOTTLED WATER

The International Bottled Water Association maintains that “of 6.1 servings of water consumed daily, 2.3 servings are bottled water” (IBWA, 2004). Burgeoning growth in the bottled water industry indicates that a significant portion of the public has enough concern about the quality, safety, and/or taste of tap water that people are willing to pay a premium for it. However, even though bottled water is frequently marketed as being safer than tap water, “Choosing bottled mineral water over tap may not offer more protection against potentially hazardous bacteria” (Warner, 2004). POU technology can produce water providing more reliable protection than bottled water in a much more convenient manner and at a fraction of the cost of bottled water.

POU TECHNOLOGY

POU technology has been embraced as a final barrier in the traditional multiple-barrier approach to protecting public health. The least complicated POU device can be placed on a countertop; other devices are threaded onto an existing faucet and can be switched between “general use” mode and “filtered, direct consumption” mode. There are also under-the-counter systems that use filtration, adsorption, and disinfection.

A variety of technologies are incorporated into POU devices, which include sediment filters, submicron filtration and activated carbon systems, and disinfection systems.

Sediment filters. Hydraulic surges and line ruptures, which cause sloughing of biofilm or create particle loading, will always occur in distribution systems. It is recommended that a 5- to 10-µm sediment filter be installed upstream of any submicron filter to avoid premature clogging of the submicron filter.

Submicron filtration and activated carbon adsorption. Many POU systems integrate activated carbon adsorption into a submicron filtration system. In addition to removing EDCs, activated carbon removes trihalomethanes and PhACs. Activated carbon filters also enhance the aesthetic appeal of water by adsorbing chlorine, thereby eliminating “chlorinous” taste.

Depending on the residual chlorine level in the distribution system, it is likely that the carbon filter will eventually develop a biological growth. This growth should not be pathogenic; however, to ensure the biological integrity of the product water, some carbon filters include a bacteriostat (Ameripure Water, 2004).

There are four categories of submicron filtration. The categories are defined based upon the micron size of the pores (GE Water, 2004):

- Microfiltration removes particles to <0.1 µm, excluding most bacteria and protozoa.
- Ultrafiltration removes particles to <0.01 µm, excluding most viruses.
- Nanofiltration removes particles to <0.001 µm. This technology will remove viruses as well as some pesticides and herbicides.
- Reverse osmosis (RO; sometimes called hyperfiltration) is a membrane technology that allows water to pass through a membrane by diffusion. It can remove contaminants from the water that are >0.0001 µm, resulting in permeate (product water) that is essentially “H2O” but devoid of the healthful minerals usually found in tap water.

Existing POU manufacturers generally use microfiltration or RO in their devices, both of which are frequently coupled with activated carbon adsorption. From an installation perspective, microfiltration is generally more attractive (and economical), because pressure from the distribution system is usually sufficient to force the water through the filtration system, whereas RO may require a
booster pump. In addition, RO generates a concentrated waste stream that must be disposed of through a plumbing connection to the home’s drain system; microfiltration does not generate this waste stream.

Disinfection. Disinfection following activated carbon adsorption, rather than a bacteriostat, is recommended for carbon filters. The two most common POU disinfectants are ozone and ultraviolet radiation.

Implementation. Should the water industry and the regulatory community universally embrace POU as a viable addition to the multiple-barrier treatment approach, what would the costs be and who would install and maintain the devices? Most NSF-certified systems retail for approximately $120. Replacement filtration cartridges run about $45/500 gal (Water Filter Comparisons, 2004). A family of four consuming 2 quarts/person/day would get about 250 days of use per filter. Original acquisition costs as well as replacement cartridge prices would be reduced significantly if purchased in bulk by a district or municipality for distribution to customers. (Harrison, 2004) Many manufacturers recommend cartridge replacement every six months; some units have indicators to notify the homeowner when it is time for replacement (Hydrotech Water, 2004). Depending on the type of unit, a homeowner with relatively basic plumbing skills could perform the installation. Although not currently regulated, many contaminants that can be economically removed using a POU device will likely be regulated in the future. At that time, the regulatory community will undoubtedly require verification that proper maintenance is occurring.

John McEncro (jmcencro@mines.edu) has worked at five water systems during the past 26 years and specializes in treatment optimization and security.

REFERENCES


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Health Effects of Premise Plumbing Problems

By Marc Edwards, PhD
Transcribed and edited from the oral presentation on Tuesday, March 27, 2007 at WQA Aquatech USA, Orlando, Florida.

The subject of this paper is a logical progression in the growing understanding about water quality. From a historical perspective, water quality was a natural selection process. Having access to a good water source for drinking meant living and thriving, which the lack of access resulted in death. In the late 1800s, John Snow started making links between specific causative factors in water and cholera. It was about that time that large scale treatment at central plants began implementing filtration and disinfection. These are rightly among the top ten engineering achievements of the twentieth century.

In the last decade or so, the United States Environmental Protection Agency (USEPA), the American Water Works Association (AWWA), and others began recognizing that one of the most important emerging issues related to public health is the effect of the distribution systems on water quality. The most studied factors in water quality degradation are those associated with the main distribution systems: big pipes, infiltration of pathogens, regrowth, backflow, permeation, and others. Premise plumbing is the final stage of getting clean water to people, and its important contribution to public health has begun receiving a due share of attention just in the last few years or so.

This paper focuses on several inherent, underappreciated and undermonitored, characteristics of premise plumbing that differentiate it from the water mains and the resulting effects on water quality degradations.

What is premise plumbing? It is the portion of the water distribution system that’s after the property line. This represents the copper and/or plastic pipes, hot water systems, and recirculation systems that occur in buildings. Unfortunately, more questions than answers exist when looking at controlling water quality in premise plumbing. One of the most important questions is if the property line is where utility and regulator responsibility ends for water quality, whose responsibility is it to make sure that the water after the property line remains potable?

A number of factors make problems in premise plumbing difficult to address. First and foremost, the problems are very expensive and complicated. Based on the property damage potential, the value of home plumbing and building plumbing systems is roughly two to five times higher than that of the main distribution system. This financial burden is falling on building owners and property owners.

Second, no collective group is funding research into these problems, so not a lot of research has been done. Understanding, of course, follows research. Third, the issue of liability and determining who’s responsible for what portion of the problem has not been defined, and worse is that no one wants responsibility for this problem.

An example of premise plumbing issues discussed at previous Water Quality Association conferences is something known as blue water. This arises from copper corrosion. One sample from California had 1300 parts per million copper in it. This was a problem that affected a very small number of newer homes in California. At the time, no one understood how this problem started or how to stop it. A big law suit resulted, generating a lot of bad press for the water utility and for the water industry and, finally, prompting some research to investigate the cause.

Copper pitting problems are another issue. The cause behind pinhole leaks, not only in copper, but also, according to our recently completed survey of the whole United States, in plastic and in galvanized pipes is unknown. The most likely cause will be due to a wide variety of factors, including corrosive water. In some cases, the levels of leaks in certain areas of the country can only be characterized as epidemics.

Figure 1 is a picture of a pipe section from a building in Washington DC. Underneath all those clamps is copper pipe demonstrating how bad this problem can get; on the order of one leak per inch.

Our research has documented many such occurrences, including instances where brand new copper pipe failed in as little as two weeks after it was installed. On a national scale, the costs of this issue across all plumbing materials, plastic, galvanized, etc., is an annual burden on US consumers of about a billion dollars. That estimate is based on a recent study funded by the USEPA, the National Science Foundation, and the AWWA. Along with leaks, mold is sometimes a problem. The leaks are very hard to find, and they’re very disconcerting to homeowners.

Besides the pipe degradation problems being expensive and complicated, they’re also very political, as evident by the USEPA’s Lead and Copper Rule compliance issues. This is not a regulation that anyone seems to strongly advocate, and certainly the water distribution industry didn’t want any part of this when it first came out. Not only can it generate a lot of bad publicity for a utility that doesn’t meet the USEPA action limit, but often, just by changing the sampling protocol, the results can be easily manipulated to show the utility is compliant when it’s really not.
Health Effects of Premise Plumbing Problems

That was the case in Washington DC some years ago, but isolated problems have also been seen in other parts of the country. In the cases of lead poisonings from water occurred in North Carolina in 2005 and 2006. The most disconcerting aspect was that some of these were documented in cities that, officially, had no violation of the USEPA Lead and Copper Rule. A careful look, however, revealed isolated cases with hazardous levels of lead.

The preceding provides some background on why premise plumbing has such an unanticipated effect on water quality despite the central treatment plant being in compliance with all standards. The next step is to consider what type of problems can arise in premise plumbing and why.

For a long time, the plumbing system in the home was viewed as a logical extension of the main distribution system that the water utilities ran, with the assumption that anything that’s good for the main system is also likely to translate to something good for the home plumbing system. The main premise of this paper is that this view is incorrect and leads to a lot of the problems that will be discussed below.

Most problems arising from premise plumbing share some common elements. First of all, the quality of water going into the home is a key ingredient. Water quality has infinite variety not only across the country and the world, but also within a distribution system, from season to season, day to day. It varies depending upon what plumbing materials are installed, and in what part of the distribution system the home is located. Second, in the unregulated environment of the home, the plumbing configurations and materials can also vary considerably.

As a result, the inherent complexity of this environment is multiplicative; on top of the variations in the incoming water quality that are occurring is the variation of how homeowners use the water, how they run their hot water system, whether they’re at home on weekends or not, as well as the plumbing materials used. This complexity is absent in the main distribution systems.

The third common element is the considerable geometric difference between the plumbing that’s in the homes and that which is in the water mains. For example, although the building distribution lines are a smaller diameter, the total length of these lines is ten times greater than the total length of water mains across the United States. The surface area per unit volume of water in the building distribution lines is also very high by comparison. Since many premise plumbing problems arise from interactions between the water and the plumbing surfaces, the building distribution lines exert a considerably greater impact on the water chemistry and water quality of the final product than the main distribution system.

Each building has a very small fraction of the total water volume distributed by the municipality, on the order of one sixtieth, because of the pipe diameter, and about one tenth if the amount of water that’s stored in water heaters and in toilets is included. The plumbing materials in the buildings are also different from the materials in the mains. Some of the more noble metals, like copper, that are used in home plumbing have catalytic reactivity with certain compounds in the water, including, chloramines. As a result, while chloramines tend to be a very stable form of disinfectant in the main water distribution system, in copper pipe, in general, chloramines disappear very quickly. Also, corrosion control strategies in the main distribution systems containing iron, steel, and concrete materials don’t automatically translate to mitigating corrosion in homes.

Figure 2 illustrates this issue of reactivity and the decay of chloramines with time in copper pipe versus a glass control pipe.

Figure 2

Maintaining a residual disinfectant all the way to the tap is a key tenet of water treatment. The residual prevents regrowth of potentially harmful microorganisms and pathogens. The study illustrated in Figure 2 compared waters in copper pipe with different ratios of chlorine to ammonia that represent a range of chloramine levels. The study also looked at water with free chlorine in copper pipe and a 4:1 ratio of chlorine to ammonia in a glass control pipe.

The glass control is representative of what might happen in a PVC pipe, which has almost no chloramines demand. Just like in the water mains, chlorine was maintained in the glass control for a period of days without much difficulty.

Conversely, in a copper pipe, almost regardless of the chlorine to ammonia ratio, the disinfectant residual disappeared very quickly. In fact, the chloramines residual was non-detectable in about eight hours.

This exact situation is occurring in many homes in the United States. The problem is that the level of reactivity of the disinfectant residual depends on water chemistry, so sometimes chloramines are in fact very stable inside copper pipes. Unfortunately, current water quality analysis protocols are not designed to look for situations when the residual is not stable.
Health Effects of Premise Plumbing Problems

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Another important factor in the availability of residual disinfectant that’s rarely taken into consideration is the stagnation of water in the home piping. Often, water in residences remains unused for long time periods. Together with the decay of the residual disinfectant, these conditions essentially turn every home in the water distribution system into a dead end.

Municipal water distribution systems are constructed to avoid dead ends either by allowing for flushing or by building in loop systems. The way that homes are operated, dead ends are an inherent problem. As a result of the dead end condition, the stagnant water, and the quickly decaying disinfectant residual, the potential for microbial regrowth is maximized.

Additionally, water inside the house often has a decreased chlorine residual because it’s either warmed up naturally in the pipes while sitting in the walls or purposefully in the water heater. The higher temperatures produce higher rates of microbiological regrowth. Microbes that occur at the tap in premise plumbing often arise from biofilms that are on pipe.

Unfortunately, in this home environment, where regrowth potential has been maximized, the sampling protocol doesn’t lend itself to the detection of these microbes. The first step in microbiological testing in the home is to remove the aerator and flush the lines for 5 or 10 minutes to try to get samples of water that are representative of the water mains. This fails to provide any information on the extent to which the regrowth problem exists in houses.

Another factor influencing water quality in premise plumbing is the irregularity in water velocity. The lack of consistent, continuous flow that exists in the water mains increases the potential for sloughing off slugs of biofilm in the pipes. Furthermore, showers can create bio aerosols, which is probably the major mode of transmission of *Legionella* and microbacteria. Typically, studies of pathogen-related problems are limited to exposure from drinking the water and the resulting gastrointestinal upset. Very few studies examine exposure through the bio aerosolization route in showers.

Unsafe plumbing configurations, i.e. plumbing that does not meet code, installed by do-it-yourself home-owners, are also a source of problems. A study in Davenport, Iowa, done by USC in 2002, found that 9.6 percent of homes have direct cross connection to a potential plumbing hazard, most often the toilet bowl. In addition, 95 percent of homes had other direct or indirect cross connections. According to the USEPA, the majority of backflow events that have been documented do not occur in the main distribution system, which is under very stringent regulations and has trained, licensed operators. In fact, 96 percent of documented backflow events occur in premise plumbing.

The service lines involved in premise plumbing are typically the point in the distribution system that has the most leaks not on a volume basis, but just in terms of sheer number. Any negative pressure in the distribution system could draw pathogens in through those leaks, just like in water mains. The difference being that with service lines, the problem is packed into one building or one house, making it even less likely to be detected by regulators. To qualify as a waterborne disease outbreak, multiple instances from multiple taps are needed. Adding to this is the issue of permeation, where certain plastic materials allow soluble compounds, benzene-type materials, to be transported directly through the pipe wall into the drinking water.

An emerging issue is the recommended operation of solar and domestic water heaters. This is a classic case of cost/benefit tradeoffs from multiple objectives. The heaters are not operated at a sufficiently high temperature to kill bacteria, so the water heater can be best thought of as a massive bacteria incubator right inside a house. The reality is harmful bacteria grow up to 122 degrees Fahrenheit, and they’re killed virtually completely at higher temperatures on the order of 140 degrees Fahrenheit. The worst possible temperature at which to operate a water heater is at 99 degrees Fahrenheit, which is body temperature, and selects microorganisms that are perfectly adapted to grow in the human body.

An example of such an organism is *Legionella*, the causative agent of Legionnaires’ disease. The Centers for Disease Control and Prevention (CDC) estimate that between 8,000 to 18,000 cases of Legionnaires’ disease occur in the US each year. About 12 percent of these cases are attributable to drinking water. Only one study tried to apportion the known *Legionella* cases among the different possible pathways of infection. Surveys from Quebec City, San Francisco, as well as others in Europe, found that anywhere between 37-60 percent of the water heaters sampled do contain *Legionella*. The disease is transmitted through the unusual pathway of inhalation or aspiration of a small amount of consumed water directly into the lungs.

One of the reasons water heaters operate at lower temperatures is to prevent scalding. A 3-4 second exposure to 140 degree F water is sufficient for an adult to get a third-degree burn. How can this concern be balanced with *Legionella* kill? Australia handles it by requiring that water heaters maintain a temperature greater than 140 deg. F, and that antiscald devices - faucets with mixing valves – are placed at each point-of-use or where potential scalding events might occur. Other countries are going to tankless water heaters, and while further study is necessary, existing research shows a very low likelihood of pathogen growth in the tankless heaters.

While the benefit of recommending that homeowners turn their water heater temperature down to 120 degrees Fahrenheit is energy savings, the tradeoff is the promotion of microbial contaminations. Deciding which issue should take precedence is not easy.

The type of water heater, gas or electric, also affects the likelihood of bacterial growth. Electric water heaters are subject to stratification. The warmest water rises to the top because it’s lightest, while the coldest water goes to the bottom. At the bottom of the water
### Health Effects of Premise Plumbing Problems

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Heater is iron sediment, which provides additional nutrients for *Legionella*. Coupled with the sediment, the movement of the colder water to the bottom of the water heater provides ideal conditions for incubating pathogens. Some studies have demonstrated a direct correlation between the presence of *Legionella* at the tap and the amount of iron sediment that gets swept out of these water heaters. Gas water heaters are heated from the bottom, eliminating the possibility for stratification, and indeed, studies have shown much less frequent occurrence of *Legionella* in those devices.

In conclusion, what’s important to remember is that premise plumbing really is a unique animal. It can’t really be treated as an extension of the distribution system. The existing sampling protocol doesn’t detect problems arising from premise plumbing; and water heater operation further complicates the water quality issue by requiring a tradeoff between energy savings, heater type, and prevention of microbiological growth.

### QUIZ 1: “Health Effects on Premise Plumbing Problems” (0.35 CPD)

<table>
<thead>
<tr>
<th>Question</th>
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| 1. Which group/organization is responsible for addressing water quality problems arising from premise plumbing? | a. AWWA  
  b. US EPA  
  c. Municipality  
  d. Homeowners |
| 2. What has been the traditional view of water treatment and water quality in premise plumbing? | a. It’s an extension of the main distribution systems  
  b. It’s the homeowner’s responsibility  
  c. It has many permutations that can affect water quality |
| 3. Which factor exerts the LEAST amount of impact on the water quality at a specific tap? | a. The water quality in the water mains leading up to a building  
  b. The total surface area of the premise plumbing pipes inside a building  
  c. The plumbing materials used in premise plumbing  
  d. The water usage patterns in a building |
| 4. What is the effect of copper pipe used in premise plumbing on the ability to maintain a chloramines disinfection residual up to the tap? | a. No effect  
  b. Improves the stability of the disinfection residual  
  c. Destabilizes the stability of the disinfection residual |
| 5. What is the effect of plastic pipe used in premise plumbing on the ability to maintain a chloramines disinfection residual up to the tap? | a. No effect  
  b. Improves the stability of the disinfection residual  
  c. Destabilizes the stability of the disinfection residual |
| 6. Why are home plumbing systems equivalent to dead ends in a distribution system? | a. Water sits unused for long periods of time  
  b. Municipal systems don’t build in return loops  
  c. The disinfectant residual is not meant to cross the property line  
  d. Water can warm up in the home’s pipes |
| 7. What, in the sampling protocol for microbiological contamination, makes problems arising from premise problems difficult to detect? | a. Samples are collected as a first draw from the tap  
  b. Samples are collected after the line has been flushed  
  c. Different sampling kits are used for premise plumbing than at the source  
  d. Samples are collected from the hot water tap, only |
| 8. If home plumbing is governed by plumbing codes, why do 96% of backflow events occur in premise plumbing? | a. Plumbing inspectors are not as vigilant in private homes  
  b. Homeowners make unsafe crossconnections in premise plumbing  
  c. Homes do not use backflow preventers  
  d. Check valves installed in homes often fail |
| 9. Where in the home distribution system are the best conditions for growth of *Legionella*? | a. Toilet  
  b. Tap aerator  
  c. Showerhead  
  d. Hot water heater |
| 10. What is the suspected route for most cases of Legionnaires’ disease? | a. Drinking water  
  b. Inhalation/aspiration in the shower  
  c. Backflow events  
  d. Cross connections |
| 11. What is the negative effect of operating domestic water heaters at 120 degrees F rather than at higher temperatures? | a. Increased scale build-up  
  b. Decreased energy efficiency  
  c. Formation of temperature-stratified water layers  
  d. Promotion of bacterial growth |
| 12. Other than energy efficiency, what is the other factor behind the recommendation for operating domestic water heaters at temperatures below 140 degrees F? | a. Decreases scale build-up  
  b. Reduces formation of temperature-stratified layers  
  c. Reduces bacterial growth  
  d. Decreases potential for scalding |
| 13. Which types of domestic water heaters are more likely to produce temperature-stratified layers? | a. Gas tank heaters  
  b. Electric tank heaters  
  c. Tankless heaters |
Removal of Arsenic from Drinking Water by Adsorptive Media


1.0 INTRODUCTION

1.1 Arsenic in Water Supplies
Arsenic occurs in combination with other ions as arsenic compounds. Unless contaminated by arsenic-bearing wastes, the arsenic concentrations in surface water supplies are normally less than the [Maximum Contaminant Limit (MCL) as specified in the Primary Standards of the Safe Drinking Water Act]. Groundwater supplies have higher arsenic concentrations which may exceed the MCL due to the exposure of the water to arsenic-bearing materials.

1.2 Arsenic Speciation
Arsenic is a common, naturally occurring drinking water contaminant that originates from arsenic-containing rocks and soil and is transported to natural waters through erosion and dissolution. Arsenic occurs in natural waters in both organic and inorganic forms. However, inorganic arsenic is predominant in natural waters and is the most likely form of arsenic to exist at concentrations that cause regulatory concern.

The valence and species of inorganic arsenic are dependent on the oxidation-reduction conditions and the pH of the water. As a general rule of thumb, arsenite, the reduced, trivalent form [As(III)], normally is found in groundwater (assuming anaerobic conditions); and arsenate, the oxidized pentavalent form [As(V)], is found in surface water (assuming aerobic conditions). This rule, however, does not always hold true for groundwater. Some groundwater samples have been found to have only As(III), others with only As(V), and still others with the combination of both As(III) and As(V). Arsenate exists in four forms in aqueous solution, depending on pH: H₂AsO₄⁻, H₃AsO₄⁻, H₂AsO₄²⁻, and AsO₄³⁻. Similarly, arsenite exits in five forms: H₂AsO₃⁺, H₃AsO₃⁻, H₂AsO₃⁻, HAsO₃²⁻ and AsO₃³⁻. The higher the pH, the fewer hydrogen ions will be bound to the arsenate/arsenite compounds.

Until recently, studies on the preservation of the arsenic species concluded that no effective methods existed for the preserving of As(III) and As(V) in water samples. Because of the lack of a good preservation method, field separation methods developed by Ficklin (1982), Clifford et al. (1983), and Edwards et al. (1998) have been used that employ an anion exchange column as the separation procedure. All the methods have been found to be effective, and their use is recommended to determine the oxidation state of the arsenic in the source water to be treated.

1.3 Removal of Arsenic
In water supplies where the arsenic level exceeds the MCL, steps should be taken to reduce that level to below the MCL. This design manual focuses on the removal of excess arsenic by using activated alumina and other adsorptive media methods. However, other treatment methods exist, such as ion exchange, membrane separation, and chemical coagulation/filtration. Also, other options, including alternate sources of supply, may offer lower cost solutions. The first option is to locate an existing water supply within the service area with known quality that complies with the arsenic MCL in addition to all other MCLs (both organic and inorganic). If another source complies with the arsenic MCL but exceeds another MCL (or MCLs), it may still be feasible to blend the two sources and achieve a water quality that complies with all MCLs. Other features associated with this option may present liabilities, including, but not limited to, high temperature or undesirable quantities of nontoxic contaminants such as turbidity, color, odor, hardness, iron, manganese, chloride, sulfate, and/or sodium.

A second option is to pump good quality water to the service area from another service area. Similar to the alternate source within the service area, this imported source can be blended. However, the costs of installing the delivery system and delivering the water become increasingly unfavorable as the distance increases, the rise in elevation increases, and/or the existence of physical barriers occurs. The reliability, the cost, and the assurance that the consumers will only use that source are factors to be considered. Another option (which includes an element of risk) is to drill a new well (or wells) within the service area. This approach should be attempted only when there is sound reason to believe that sufficient quantity of acceptable quality water can be located. The cost (both capital and operating) of a new well should not exceed the cost of treating the existing source. Other options such as “point-of-use” treatment systems are viable alternatives. However, the treatment reliability of such units cannot be assured unless there are stringent controls governing their operation and maintenance. Also, the problem of assuming that all users consume only water that has been treated where untreated water also is available should be addressed.
Removal of Arsenic from Drinking Water by Adsorptive Media

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2.0 ARSENIC REMOVAL BY ADSORPTIVE MEDIA TREATMENT METHODS

2.1 Introduction
This chapter provides an overview of the design considerations that are applicable to adsorptive media treatment systems. The design choices are as follows:

1. Selection of adsorptive media
2. Treatment with or without pH adjustment
3. Treatment media regeneration vs. treatment media disposal
4. Manual vs. automatic operation (or semiautomatic operation)

2.2 Granular Adsorptive Media
This design manual focuses on the implementation of the granular adsorptive media method for the selective removal of arsenic from water supplies with or without pH adjustment and with or without spent media regeneration. The treatment method example presented employs activated alumina media, which utilizes a single treatment train and consists of two downflow pressure vessels in series. This method is applicable to the use of any other adsorptive media, and, therefore, one adsorptive media can be replaced with another without replacing or making major modifications to an installed treatment system.

Activated alumina has a long history of use as an adsorptive treatment technology for arsenic removal. The media is a byproduct of aluminum production. It is primarily an aluminum oxide that has been activated by exposure to high temperature and caustic soda. The material is extremely porous and has a high average surface area per unit weight (350 m2/g). The capacity for arsenic removal by activated alumina is pH-dependent, with the maximum removal capacity achieved at pH 5.5. Adjusting the pH of the source water, therefore, provides removal capacity advantages. As the pH deviates from the 5.0-6.0 range, the adsorption capacity for arsenic decreases at an increasing rate. Process demonstrations have shown that arsenic removal capacity has been reduced by more than 15% at pH 6.0 compared to that of pH 5.5 (Rubel, 1984).

Fluoride, selenium, and other inorganic ions and organic molecules also are removed by the same pH adjustment activated alumina process. The process, however, is preferential for arsenic at the optimum pH level of 5.5. Other ions that compete with arsenic for the same adsorptive sites at other pH levels are not adsorbed in the pH range of 5.0-6.0. Included are silica and hardness ions that are adsorbed in the pH range of 7-10.

Activated alumina can be either regenerated or can be replaced with new media when the selected breakthrough point is reached. At the optimum pH for arsenic removal, fluoride, selenium, some organic molecules, and some trace heavy metal ions are adsorbed; however, these are also completely regenerated along with arsenic. Because these ions compete for the same adsorptive sites with arsenic, their presence might deplete the alumina capacity for arsenic. When excess fluoride and arsenic are present in the water supply, a special treatment technique is required (Rubel and Williams, 1980).

Newly developed adsorptive media for arsenic removal consist primarily of iron-based materials or iron-modified activated alumina products. Some of these materials are not capable of regeneration and, thus, are used solely on a replacement basis (throwaway). Some of these media, mainly the iron-based products, have demonstrated arsenic removal capacities that exceed that of activated alumina, particularly at pHs above the optimum pH 5.5 level for alumina treatment. The adsorptive capacity of these new materials also is affected by pH; however, their pH sensitivity does not resemble that of activated alumina. The benefit of pH adjustment may come more from the elimination of competition for adsorptive sites by ions such as silica and phosphate. Consequently, these materials can be employed economically on a spent media replacement basis without the incorporation of pH adjustment chemicals and equipment. As new adsorptive media products and technology evolve, more efficient and economical arsenic removal treatment systems will become available.

2.2.1 pH Adjustment System
The adsorptive capacity of many adsorptive media, particularly activated alumina, is pH sensitive; removal capacity increases with decreasing pH. Employing pH adjustment, therefore, generally provides cost advantages regardless of whether the media is regenerated or replaced. Because the pH adjustment chemicals are usually the same chemicals that are used for regeneration, it is generally advantageous to couple regeneration with pH adjustment systems when the media can be regenerated.

The advantages of using an adsorptive system with pH adjustment and regeneration or replacement of spent media are as follows:

1. System is low-cost and simple to operate.
2. System requires minimal operator attention (part time) during treatment runs.
3. System can employ manual operation and is adaptable to automatic operation.
4. Activated alumina media system has longer treatment runs (greatest removal capacity). Other media may have the same advantage.
5. Activated alumina system removes As(III) and As(V) at pH 5.5 (author’s experience).
The disadvantages of using the pH adjustment method are as follows:

1. System requires chemical feed equipment and the storage and handling of corrosive chemicals (acid and caustic) for pH adjustment of raw water and readjustment of treated water.
2. pH adjustment chemicals increase inorganic ions and total dissolved solids (TDS) in the treated water. Secondary MCLs must be considered.
3. System with regeneration of spent media requires disposal of wastewater.

2.2.2 Non-pH Adjustment System

Some adsorptive media do not provide significant gains in removal capacity by lowering pH as does activated alumina. These materials, as well as activated alumina, are used without pH adjustment with good results particularly by very small systems that do not want to handle pH adjustment chemicals. In the case where pH adjustment is not used, regeneration is not advantageous or practical. Consequently, a non-pH adjustment system usually is coupled with replacement of spent media only.

The advantages of utilizing an adsorptive system without pH adjustment or regeneration of spent media are as follows:

1. System is inexpensive to install and, depending on the arsenic concentration and water quality (competitive ions, etc.), operational cost may be low.
2. System does not require chemical feed and storage equipment. The handling of corrosive chemical is not required.
3. System requires minimal operator attention (part time) during treatment runs.
4. System can employ manual operation, and automatic operation may not be necessary.
5. If arsenic breakthrough occurs, the arsenic concentration in the treated water will not exceed that of the raw water.
6. Disposal of spent arsenic-bearing activated alumina and iron-based media products can be accomplished as a nonhazardous waste (i.e., media passes Toxicity Characteristic Leaching Procedure [TCLP] test).

The disadvantages of utilizing the non-pH adjustment method without regeneration of spent media are as follows:

1. System has lower adsorptive removal capacity, particularly an activated alumina system, resulting in much shorter treatment runs.
2. Other ions (e.g., silica, phosphate, etc) generally compete for adsorption sites with arsenic. The extent of competition depends on the pH of the source water.
3. System requires more frequent media replacement. Expensive materials could result in costly operation.

2.3 Treatment With or Without pH Adjustment

Prior to start of design, the best arsenic removal treatment method for a given application should be selected. Not all adsorptive media may be pH-sensitive as activated alumina. The manufacturers of these materials advise that, even though pH adjustment does enhance arsenic removal performance, it is not required to achieve cost-effective results. The selection of adsorptive media will rely on either the manufacturer’s media performance claims or the development of independent technical performance data through field pilot testing or other means. Though costly, it is highly recommended that technical data be collected for a given application.

The decision to adjust treatment pH is determined in the conceptual design phase of the project. If the decision is not to incorporate pH adjustment, then the capital cost for the treatment system is reduced and regeneration of adsorptive media is eliminated. If the decision is to incorporate pH adjustment for the treatment process, then the capability to regenerate the adsorptive media in place of media replacement is available (but optional).

2.4 Treatment Media Regeneration vs. Treatment Media Disposal

The decision to regenerate or replace spent treatment media for each system should be made based upon economic, technical, and/or aesthetic operating requirements. A major factor to be evaluated is the disposal of the regeneration wastewater.

Activated alumina and some other adsorptive media can be regenerated chemically for reuse rather than being disposed of after arsenic removal capacity has been exhausted. For regenerable treatment media, an economic/technical evaluation should be performed to determine whether to provide regeneration capability for the treatment system. If the treatment plant is capable of adjusting the raw and treated water pH, then the requirement to handle, store, and feed corrosive chemicals (acid and caustic) is already included. However, for a media replacement system that does not require major chemical storage equipment, the procurement of more costly packaging of pH adjustment chemicals will be required.

Regeneration involves removing the arsenic from the treatment media, precipitating the dissolved arsenic in the regeneration wastewater, dewatering the arsenic-bearing precipitated solids, and finally disposing of waste solids and liquids in a method acceptable to the presiding regulatory agency.

Due to increased capacity for arsenic removal resulting from pH adjustment, the implementation of a pH adjustment treatment system may be justified with or without regeneration of the spent adsorptive media.

Treatment media regeneration is more likely to be economically justified for systems with high flow rates and high raw
water arsenic concentrations due to the resulting rapid consumption of arsenic capacity. The higher the arsenic concentration in the raw water, the higher the probability that regeneration of treatment media will be economically desirable. Each evaluation should include the variables that affect the cost of spent media regeneration vs. replacement.

Some adsorptive media are not capable of regeneration and, upon exhaustion of arsenic capacity, must be removed for disposal. For systems that are not large enough to economically justify the processing of the regeneration wastewater, regeneration generally is not a consideration. However, very small systems with the capability to economically dispose of regeneration wastewater should evaluate this option.

Adsorptive media with very high arsenic removal capacities can economically justify media replacement rather than regeneration, even though the media can be regenerated.

Chemical regeneration may not be economical without implementation of the same chemicals for treatment pH adjustment. Therefore, the regeneration option should be discarded if water utilities prefer not to handle corrosive chemicals, or advocate that addition of treatment chemicals might degrade the quality of the potable water, or for other economical, technical, or aesthetic concerns.

2.5 Manual vs. Automatic Operation

The water utility owner should be informed of the advantages and disadvantages of operational options prior to finalizing the decision on mode of operation. The system can be operated manually, automatically, or semiautomatically. Automatic operation reduces the operator effort, but increases the cost of instrumentation and control equipment as well as the skill level required of the operator who must be able to maintain more sophisticated equipment.

Treatment systems utilizing adsorptive media are suitable for manual operation. That operational mode requires the treatment plant operator to accomplish the following:

2. Start/stop and adjust rate of chemical feed to control pH. Monitor pH (for systems with treatment process pH adjustment only).
3. Monitor and adjust system operating pressure.
4. Start/stop/control each backwash and regeneration step (for systems with spent media regeneration only).
5. Monitor and adjust water levels in reservoirs and other containment facilities.
6. Monitor arsenic concentrations for raw water, treated water, and intermediate sample points.

A fully automatic instrumentation and control system includes a programmable logic controller (PLC), an operator interface (screen with graphics), software, automatic instrumentation (sensors, transmitters, controllers, alarms, electrical conductors, pneumatic tubing, etc.), and automatically controlled equipment (valves, pumps, chemical feed pumps, air compressor, etc.). The instruments can monitor pH, flow, level, pressure, and temperature. Arsenic concentration analyses require manual laboratory procedures.

Semiautomatic operation entails automating any part of the instrumentation and control functions, and the remainder is accomplished manually. Not included are the PLC, operator interface, and required software. This operational mode reflects choices made by the owner with the advice of the designer. The choices require analysis of risk and treatment process efficiency vs. investment in equipment and labor. This design manual presents information regarding instrumentation and control functions, all of which can be accomplished automatically or manually. The only exception is the laboratory analysis requirement for determination of arsenic concentration in raw water, treated water, wastewater, and at intermediate sample points.

Automatic operation is only practical for systems employing treatment process pH adjustment and spent media regeneration. Semiautomatic operation is applicable to systems that employ treatment process pH adjustment with either spent media regeneration or replacement. For systems without treatment process pH adjustment, automatic operation is not practical. For those systems without treatment process pH adjustment, semiautomatic features for monitoring flow, pressure, and storage liquid levels may be desirable.

References


1. Which form of arsenic is most likely to exist at concentrations exceeding MCLs in natural water?
   a. Pentavalent, As(V)
   b. Trivalent, As(III)
   c. Organic arsenic
   d. Inorganic arsenic

2. What’s the optimum pH for arsenic removal by activated alumina?
   a. 5.0
   b. 5.5
   c. 6.0
   d. 6.5

3. By what percent does removal capacity of activated alumina decrease at 0.5 pH units above the optimum pH range?
   a. 10%
   b. 15%
   c. 20%
   d. 25%

4. Activated alumina can remove a number of molecules and ions besides arsenic that can interfere with arsenic removal. Why is it a good option, regardless?
   a. Preferentially adsorbs arsenic at the optimum pH range
   b. The typically higher concentrations of arsenic than the other molecules helps it win the competition for binding sites
   c. Adsorptivity of the non-arsenic molecules is reversible
   d. Arsenic adsorbs more strongly than the other ions/molecules

5. What type of media has been shown to exceed arsenic removal capacity of alumina?
   a. Granular activated carbon
   b. Silver-impregnated alumina
   c. Iron-based media
   d. Manganese-based media

6. What factor makes the use of regenerable media easier in systems using pH adjustment?
   a. Same chemicals are used for both processes
   b. Decreases presence of other inorganic media in product water
   c. Less waste water generated
   d. Less expensive than media replacement

7. What advantage do non-pH-adjustment systems offer over pH-adjustment systems?
   a. Can use media that’s more selective for arsenic
   b. Lower installation cost
   c. System always fully automated, requiring little operator oversight
   d. Longer treatment runs

8. Which factor has the greatest impact on the choice between media replacement and regeneration?
   a. Storage of pH-adjusting chemicals
   b. Cost of pH-adjusting chemicals
   c. The need for OSHA training for operators
   d. Disposal of regeneration waste water

9. Which factor most impacts what makes regenerating media more economic than replacing media?
   a. On-site availability of pH-adjustment chemicals
   b. Higher arsenic concentration in raw water
   c. Availability of trained operators
   d. System automation

10. Which parameter cannot be monitored by instruments in a fully automated instrumentation and control system?
    a. Arsenic concentration analysis
    b. pH
    c. Flow rate
    d. Pressure drop
A Brief Introduction to Centrifugal Pumps

By Joe Evans, PhD
Edited with the author’s permission.

INTRODUCTION
Definition & Description
By definition, a centrifugal pump is a machine. More specifically, it is a machine that imparts energy to a fluid. This energy infusion can cause a liquid to flow, rise to a higher level, or both.

The centrifugal pump is an extremely simple machine. It is a member of a family known as rotary machines and consists of two basic parts: 1) the rotary element or impeller and 2) the stationary element or casing (volute). Figure 1 is a cross section of a centrifugal pump and shows the two basic parts.

A Very Brief History
The centrifugal pump was developed in Europe in the late 1600’s and was seen in the United States in the early 1800’s. Its widespread use, however, has occurred only in the last seventy-five years. Prior to that time, the vast majority of pumping applications involved positive displacement pumps.

The increased popularity of centrifugal pumps is due largely to the comparatively recent development of high-speed electric motors, steam turbines, and internal combustion engines. The centrifugal pump is a relatively high-speed machine, and the development of high-speed drivers has made possible the development of compact, efficient pumps.

Since the 1940’s, the centrifugal pump has become the pump of choice for many applications. Research and development has resulted in both improved performance and new materials of construction that have greatly expanded its field of applicability. It is not uncommon today to find efficiencies of 93%+ for large pumps and better than 50% for small fractional horsepower units.

Modern centrifugal pumps have been built to meet conditions far beyond what was thought possible fifty to sixty years ago. Pumps capable of delivering over 1,000,000 gallons per minute at heads of more than 300 feet are common in the nuclear power industry. And, boiler feed pumps have been developed that deliver 300 gallons per minute at more than 1800 feet of head.

Theory
Centrifugal Force
In operation, a centrifugal pump “slings” liquid out of the impeller via centrifugal force.

A classic example of the action of centrifugal force is shown below in Figure 2. Here, a pail of water is swinging in a circle. The swinging pail generates a centrifugal force that holds the water in the pail.

Now, if a hole is bored in the bottom of the pail, water will be thrown out. The distance the stream carries (tangent to the circle) and the volume that flows out (per unit time) depends upon the velocity (in ft/sec) of the rotating pail. The faster the pail rotates, the greater the centrifugal force and, therefore, the greater the volume of water discharged and the distance it carries.

The description above could be considered that of a crude centrifugal pump (sans volute, of course). It demonstrates that the flow and head (pressure) developed by a centrifugal pump depends upon the rotational speed and, more precisely, the peripheral velocity of its impeller (pail).
Peripheral Velocity & Head
Gravity is one of the more important forces that a centrifugal pump must overcome. Here, the relationship between final velocity, due to gravity, and initial velocity, due to impeller speed, is a very useful one.

If a stone is dropped from the top of a building, its velocity will increase at a rate of 32.2 feet per second for each second that it falls. This increase in velocity is known as acceleration due to gravity. Therefore, ignoring the effect of air resistance on the falling stone, the velocity at which it will strike the ground can be predicted based upon its initial height and the effect of acceleration due to gravity. The equation that describes the relationship of velocity, height, and gravity as it applies to a falling body is:

\[ v^2 = 2gh \]

Where:
- \( v \) = The velocity of the body in ft/sec
- \( g \) = The acceleration due to gravity @ 32.2 ft/sec/sec (or ft/sec^2)
- \( h \) = The distance through which the body falls

For example, if a stone is dropped from a building 100 feet high:

\[ v^2 = 2 \times 32.2 \text{ ft/sec}^2 \times 100 \text{ ft} \]
\[ v = 80.3 \text{ ft/sec} \]

The stone, therefore, will strike the ground at a velocity of 80.3 feet per second.

This same equation allows determination of the initial velocity required to throw the stone to a height of 100 feet. This is the case because the final velocity of a falling body happens to be equal to the initial velocity required to launch it to height from which it fell. In the example above, the initial velocity required to throw the stone to a height of 100 feet is 80.3 feet per second, the same as its final velocity.

The same equation applies when pumping water with a centrifugal pump. The velocity of the water as it leaves the impeller determines the head developed. In other words, the water is “thrown” to a certain height. To reach this height it must start with the same velocity it would attain if it fell from that height.

Rearranging the falling body equation to solve for height:

\[ h = \frac{v^2}{2g} \]

Now the height to which a body (or water) will rise given a particular initial velocity can be determined. For example, at 10 ft per sec:

\[ h = 10 \text{ ft/sec} \times 10 \text{ ft/sec} / 2 \times 32.2 \text{ ft/sec}^2 \]
\[ h = 100 \text{ ft}^2/\text{sec}^2 / 64.4 \text{ ft/sec}^2 \]
\[ h = 1.55 \text{ ft} \]

If this were tried with several different initial velocities, an interesting relationship would be observed between the height achieved by a body and its initial velocity. This relationship is one of the fundamental laws of centrifugal pumps and will be reviewed, in detail, a little later. The above formulae can be used to calculate the impeller diameter necessary to develop a specific head for a pump with known rate of rotation (RPM). As a finale to this section, consider the practical application below.

Problem: For an 1800 RPM pump, find the impeller diameter necessary to develop a head of 200 feet.

First, find the initial velocity required to develop a head of 200 feet:

\[ v^2 = 2 \times 32.2 \text{ ft/sec}^2 \times 200 \text{ ft} \]
\[ v^2 = 12880 \text{ ft}^2/\text{sec}^2 \]
\[ v = 113 \text{ ft/sec} \]

Next, calculate the number of rotations the impeller undergoes each second:

\[ 1800 \text{ RPM} / 60 \text{ sec} = 30 \text{ RPS} \]

Finally, compute the number of feet a point on the impellers rim travels in a single rotation:

\[ 113 \text{ ft/sec} / 30 \text{ rotations/sec} = 3.77 \text{ ft/rotation} \]

Since feet traveled per rotation is the same as the circumference of the impeller, the diameter of the impeller can be calculated as follows:

\[ \text{Diameter} = \frac{\text{Circumference}}{\pi} \]
\[ \text{Diameter} = 3.77 \text{ ft} / 3.1416 \]
\[ \text{Diameter} = 1.2 \text{ ft or 14.4 in} \]

Therefore, an impeller of approximately 14.4” turning at 1800 RPM will produce a head of 200 feet.

THE PERFORMANCE CURVE
Once a pump has been designed and is ready for production, it is given a complete and thorough test. Calibrated instruments are used to gather accurate data on flow, head, horsepower, and net positive suction head required. This curve is called the Characteristic Curve because it shows all of the operating characteristics of a given pump. The curve in Figure 3 is an example.

Figure 3
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The method of reading a performance curve is the same as for any other graph. For example, in Figure 3, to find the head, horsepower and efficiency at 170 GPM, locate 170 GPM on the x-axis (horizontal) and read the corresponding data on the y-axis (vertical). The point on the Head-Capacity curve that aligns with the highest point on the efficiency curve is known as the Best Efficiency Point (BEP). In Figure 3, it occurs at approximately 170 GPM and 125 feet Total Dynamic Head (TDH).

For publication purposes, it is much more convenient to draw several curves on a single graph, as in Figure 4. This presentation method shows a number of Head-Capacity curves for one speed and several impeller diameters or one impeller diameter and several different speeds for the same pump. This type of curve is called an Iso-Efficiency or Composite Characteristic Curve. The efficiency and horsepower curves are represented as contour lines. Also the Net Positive Suction Head Required (NPSHR) curve applies only to the Head-Capacity curve for the full size impeller, in this case, 6 1/16 inches.

NPSHR will increase somewhat for smaller diameters. The curve below is a typical Composite Curve.

A pump is typically designed for one specific condition, but its efficiency is usually high enough on either side of the design point to accommodate a considerable capacity range. Often, the middle one-third of the curve is suitable for application use.

Different pumps, although designed for similar head and capacity, can vary widely in the shape of their Characteristic Curves. For instance, if two pumps are designed for 200 GPM at 100 feet Total Dynamic Head (TDH), one may develop a shut-off head of 110 feet (pump 1) while the other may develop a shut-off head of 135 feet (pump 2). Pump 1 is said to have a flat curve while the pump 2 is said to have a steep curve. The steepness of the curve is judged by the ratio of the head at shut-off to that at the best efficiency point, i.e. 110 feet/100 feet TDH for pump 1 vs. 135 feet/100 feet TDH for pump 2. Each type of curve has certain applications for which it is best suited.

Operation in Series (Booster Service)

When a centrifugal pump is operated with a positive suction pressure, the resulting discharge pressure will be the sum of the suction pressure and the pressure normally developed by the pump when operating at zero suction pressure. It is this quality of a centrifugal pump that makes it ideally suited for use as a booster pump. This quality also makes it practical to build multistage (multiple impeller) pumps. A booster pump takes existing pressure, whether it be from an elevated tank or the discharge of another pump, and boosts it to some higher pressure.

Two or more pumps can be used in series to achieve the same effect. Figure 5 below shows the curves for two identical pumps operated in series. Both the head and horsepower at any given point on the capacity curve are additive. This increases the product water pressure, but maintains the same capacity (in GPM) as that of the pump with the smaller capacity.

The composite curve shown in Figure 4 is read in much the same manner as the curve in Figure 3. Head is read exactly the same way; however, efficiency must be interpolated since the Head-Capacity curve seldom falls exactly on an efficiency contour line. Horsepower can also be interpolated as long as it falls below a horsepower contour line. If the Head-Capacity curve intersects or is slightly above the horsepower contour line, brake horsepower may need to be calculated. NPSHR is found in the same manner as head.

Many operating points will fall between the various curves, so it is important to understand a composite curve well enough to interpolate and find the approximate values.
Parallel Operation

Two or more pumps may also be operated in parallel. This, too, is considered a booster operation, but of flow capacity rather than pressure. The curves developed during parallel operation are illustrated below in Figure 6.

Figure 6

If, for example, the pump speed were doubled:

1) Capacity will double
2) Head will increase by a factor of 4 (2 to the second power)
3) Brake horsepower will increase by a factor of 8 (2 to the third power)

These principles apply regardless of the direction (up or down) of the speed or change in diameter.

Consider the following example. A pump operating at 1750 RPM, delivers 210 GPM at 75 feet TDH, and requires 5.2 brake horsepower. What will happen if the speed is increased to 2000 RPM? First we find the speed ratio.

Speed Ratio = 2000/1750 = 1.14

From the laws of Affinity:

1) Capacity varies directly or:
   \[ 1.14 \times 210 \text{ GPM} = 240 \text{ GPM} \]

2) Head varies as the square or:
   \[ 1.14 \times 1.14 \times 75 = 97.5' \text{ TDH} \]

3) BHP varies as the cube or:
   \[ 1.14 \times 1.14 \times 1.14 \times 5.2 = 7.72 \text{ BHP} \]

Theoretically the efficiency is the same for both conditions. By calculating several points a new curve can be drawn.

Whether it be a speed change or change in impeller diameter, the Laws of Affinity give results that are approximate. The discrepancy between the calculated values and the actual values obtained in test are due to hydraulic efficiency changes that result from the modification. The Laws of Affinity give reasonably close results when the changes are not more than 50% of the original speed or 15% of the original diameter.

Joe Evans lives in beautiful Rhododendron, Oregon and works for PumpTech Inc. Since entering graduate school, a continuing interest has been one of computer control of mechanical and electronic systems. It began with the introduction of the minicomputer, in the late sixties, and continued with the advent of the PC and PLC in the eighties and nineties. He accidentally entered the pump industry in 1985, has been trapped there since. He is passionate about the sharing of knowledge and its ability to replace memorization with understanding.

To read the remainder of this article and other information by Dr. Evans, please go to www.pumped101.com.
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QUIZ 3: “A Brief Introduction to Centrifugal Pumps” (0.40 CPD)

1. What is the purpose of impellers in a centrifugal pump?
   a. To increase the velocity of the liquid as it exits the pump
   b. To remove turbulence from the liquid as it exits the pump
   c. To reduce the centrifugal force acting on the liquid as it exits the pump
   d. To reduce the friction of the liquid as it exits the pump

2. What developments have led to increased popularity of centrifugal pumps?
   a. The development of high speed drivers
   b. The ability to impart greater suction lift to liquids
   c. The ability to impart greater velocity to liquids
   d. The ability to reduce the friction of liquids

3. Based on the centrifugal force example in the article, which property of the discharged liquid is affected by faster rotation of the impellers?
   a. The distance the liquid travels
   b. The friction of the liquid
   c. The turbulence of the flow
   d. The circular flow path characteristic

4. What affects the head developed by water as it leaves the pump?
   a. The velocity of the water
   b. The volume of the water
   c. The horizontal distance it travels
   d. The vertical distance it travels

5. What information can be calculated for a pump using a known rate of rotation of the impeller and the required developed head?
   a. The required diameter of the impeller
   b. The required width of the volute
   c. The number of impellers required
   d. The required circumference of the pump

6. Based on the graph in Figure 3, what is the maximum flow rate (in GPM) that the illustrated pump can provide at the maximum percent efficiency?
   a. 60
   b. 120
   c. 180
   d. 240

7. Based on the graph in Figure 4, which configuration of impeller diameter and flow rate will offer the maximum pressure at the highest percent efficiency?
   a. 5” impeller, 105 GPM
   b. 5 1/2” impeller, 130 GPM
   c. 5 1/2” impeller, 158 GPM
   d. 6 1/16” impeller, 155 GPM

8. Applications requiring an increase in head beyond what a single pump can provide, necessitate the use of:
   a. Alternating pump operations
   b. Series pump operations
   c. Parallel pump operations

9. Applications requiring an increase in flow capacity (in GPM) beyond what a single pump can provide, necessitate the use of:
   a. Alternating pump operations
   b. Series pump operations
   c. Parallel pump operations

10. Which factor is typically varied to adjust the performance of a centrifugal pump?
    a. The operating voltage of the pump
    b. The impeller diameter
    c. The width of the volute
    d. The temperature of the water

11. According to the affinity laws, if the pump driver speed (in RPM) increases by a factor of 2, how much will the head increase?
    a. By a factor of 2
    b. By a factor of 3
    c. By a factor of 4
    d. By a factor of 8

12. If a pump operating at 1800 RPM requires 7.0 brake horse power, what is the required brake horse power for the same pump operating at 2100 RPM?
    a. 7
    b. 11
    c. 49
    d. 343

13. Under which of the conditions listed below will calculations based on Laws of Affinity NOT give reasonable close to actual results?
    a. <30% change in speed and <5% change in diameter
    b. <40% change in speed and <40% change in diameter
    c. <50% change in speed and <15% change in diameter
    d. <60% change in speed and <20% change in diameter
Instructions
Please use the answer sheet below to record the correct answers. When you have completed the quizzes you’d like graded, detach the answer sheet from the booklet and mail it to the address below. The answers must be 70% correct to earn credit. These quizzes may also be taken online at http://training.wqa.org/2010edkitqz/index.htm.

WQA 2010 Educational Newsletter Quiz Answer Form

FIRST NAME ____________________________________________ LAST NAME ____________________________________________

COMPANY NAME ____________________________________________

COMPANY ADDRESS ____________________________________________

CERTIFICATION ID# ____________________________________________

Please use blue or black ink. Shade Circles Like This Not Like This

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When you have completed the quiz, detach the answer sheet from the booklet and mail it to:

Water Quality Association • Attn: Education Dept.
4151 Naperville Road • Lisle, Illinois 60532-3696
OR Fax to 630 505 9637