A brief history of water filtration/sedimentation

Larry W. Mays

ABSTRACT

For millennia the search for ‘pure’ water has been pursued by humans. Criteria for purity have become more complex, more rigid, and more quantitative over time; however, the principles, methods, and material for purifying water have remained remarkably similar from the earliest recorded information of 2000 BC. The scope of this paper is to present a brief history of water filtration and sedimentation practices for potable water management extending from the ancient times to the 19th century. It is not an exhaustive presentation, but instead presents some of the most important advances in water supply since the beginning of human’s quest for pure water.

M. N. Baker and M. J. Taras in 1981 presented an excellent overview of this quest, especially during the 17th to the 20th century.

Key words | Bronze Age, filtration, Greeks, Middle Ages, Romans, sedimentation

INTRODUCTION

The ancient Sanskrit writings (around 2000 BC) concerning medical treatment, give evidence of the first writings of water purification. From the Sus’ruta Samhita, ‘impure water should be purified by being boiled over a fire, or being heated in the Sun, or by dipping a heated iron into it, or it may be purified by filtration through sand and coarse gravel and then allowed to cool’. The Sanskrit Ous-ruta Sanghita included, ‘It is good to keep water in copper vessels, to expose it to sunlight, and filter through charcoal’, according to Francis Evelyn Place (1905) who studied Sanskrit medical lore.

BRONZE AGE

According to Defner (1921), a strange, oblong device with an opening in one of its ends, was used to treat domestic water (Figure 1(a)). The device was constructed in a similar manner and with the same material as terracotta water pipes. Spanakakis (1981) theorized that this device was a hydraulic filter which was probably connected to a water supply reservoir by a rope passing through its outside holes. Its operation was based on the availability of local, high speed, turbulent conditions in order to continuously clean the porous surface thus allowing the continuous flow of filtered water to the jar. For cleaning purposes after extensive solids accumulation, it was possible to release it from the pipe end by loosening the rope in the holes. Figure 1(b) shows an Egyptian clarifying device pictured in the tomb of Amenophis II and later in the tomb of Rameses II. This device allowed impurities to first settle out of the water, the clarified water then was siphoned off and stored for later use.

The Minoan culture flourished during the Bronze Age in Crete. A systematic evolution of water management in ancient Greece began in Crete during the early Bronze Age, i.e. the Early Minoan period (ca. 3200–2150 BC). Wells, cisterns, water distribution systems, fountains, and even recreational facilities existed. In prehistoric Crete rivers and springs provided people with water. At the start of the Early Minoan period II (ca. 2900–2300 BC), a variety of technologies such as wells, cisterns, and aqueducts were used. Also the Minoan architecture included flat rooftops, light wells, and open courts, all of which played an important role in water management. The rooftops and open courts acted as catch basins to collect rainwater from

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which it flowed to storage areas or cisterns. The concepts of sedimentation basins (tanks) was used in several locations including Tylissos, Agia Triadha, and Knossos, which are illustrated in Figures 2(a)–(c), respectively. Figure 2(a) shows the small sedimentation basin at Tylissos, used for the removal of suspended solids from the water before it flows in the small channel to the cistern where it is stored. Figure 2(b) shows a sediment basin downstream of delivery channels in Agia (Hagia) Triadha. Figure 2(c) shows the small stepped water channel along the stairway and the sedimentation basin (desilting basin). The small channel consisted of a series of parabolic-shaped stepped chutes that conveyed rainwater down to the sedimentation basin. The shape of the stepped chutes would have slowed down the flow as it progressed downwards.

Water for Tylissos was transported through an aqueduct to the three Minoan houses from the Agios Mama Spring for a distance of about 3 km. Terracotta infiltration devices (cone-shaped) were discovered at Agios Mama, the location of the spring from where water was transported to Tylissos village. These devices were filled with charcoal, thus most likely playing the role of activated carbon treatment processes in removing both organic and inorganic constituents (Mays 2010).

GREEKS

Hippocrates (460–377 BC), the Greek physician, wrote the first work on public hygiene (Air, Water, and Places) in
which he noted that water differed in quality (taste and weight) and that it could be purified. His purification process, called the ‘Hippocrates sleeve’, was to use a cloth bag through which he poured the water after it was boiled to trap sediments that caused bad taste and smell. This device was used for his patients.

The water supply system to Pergamum (Pergamon) that was built by the Hellenistic Greeks and the Romans certainly was one of the most impressive ever built by the ancients. The third aqueduct, the Madradag aqueduct, was built to the acropolis and was apparently built by Eumenes II (197–159 BC). This 50 km (Fahlbusch 2010) long aqueduct was constructed of a triple terracotta pipeline of approximately 0.18 m inner diameter with a wall thickness of 3.5 cm and 50–60 cm pipe segments. The last stretch of 3.5 km of aqueduct was a lead pipe siphon under a maximum pressure of 200 m. No sign of the lead pipes has survived, however soil samples close to the pipeline location proved to have a lead content 50 times greater than soil samples further away (Fahlbusch 2010). The three pipelines ran in parallel until they reached a header tank at an elevation of 376 m on the southern slope of Mount Hagios Georgios, which is north of Pergamon. The header tank consisted of two adjacent chambers of 3.62 × 1.21 m each (Fahlbusch 2010). The pipes of the triple pipeline aqueduct merged into the northeastern corner of the first chamber. Water flowed through the first chamber then through the second chamber into a pressure pipeline from the southeastern corner of the second chamber. The enlarged cross-sections of the chambers as compared with the pipe diameters allowed them to function as settling tanks. From the second chamber an inverted siphon was used to transport water from the header tank to the acropolis with a maximum pressure height of approximately 190 m water column (Fahlbusch 2010). The exact point where the double siphon terminated on the acropolis is not known.

ROMANS

Springs were the most common sources of water for the Romans. Water sources included not only springs, percolation wells, and weirs on streams, but also reservoirs that were developed by building dams. To properly discuss Roman water supply it is important to be aware of the treatises of Marcus Vitruvius Pollio, a Roman architect and engineer who lived in the first century BC. His ‘Ten Books on Architecture’ or ‘De Architectura’ (translation by Morgan 1914), in Book VIII (Water Supply) discussed the various elements of water supply. In various chapters of Book VIII, Vitruvius addressed the quality of water:

Chapter III (Various Properties of Different Waters):
20. Then there are springs in which wine seems to be mingled, like the one in Paphlagonia, the water of which intoxicates those who drink of the spring alone without wine. …
21. In Arcadia, is the well-known city of Clitor, in whose territory is a cave flowing with running water, which makes people who drink of it become abstemious. …
22. In the island of Zeas is a spring of which those who thoughtlessly drink lose their understanding, and an epigram is cut there to the effect that a draught from the spring is delightful, but that he who drinks will become dull as a stone. …
23. At Susa, the capital of the Persian kingdom, there is a little spring, those who drink of which lose their teeth. …
24. There are also in some places springs which have the peculiarity of giving fine singing voices to the natives, as at Tarsus in Magnesia, and in other countries of that kind. …

Chapter IV (Tests of Good Water)
1. Springs should be tested and proved in advance in the following ways. …
2. And if green vegetables cook quickly when put into a vessel of such water and set over a fire, it will be proof that the water is good and wholesome. …

Chapter V (Aqueducts, Wells, and Cisterns):
1. There are three methods of conducting water, in channels through masonry conduits, or in lead pipes, or in pipes of baked clay. …
10. Clay pipes for conducting water have the following advantages. … Secondly, water from clay pipes is much more wholesome than that which is conducted through lead pipes, because lead is found to be harmful
for the reason that white lead is derived from it, and this is said to be hurtful to the human system. …

The two story, four-chambered, catch basin on the Roman aqueduct Virgo (Rome) is illustrated in Figure 3. The piscina limaria (settling tank) on the Aqua Virgo aqueduct at the Pincian Hill in Rome is illustrated in Figure 4.

**MIDDLE AGES**

Further advancements in water filtration/sedimentation technology ended, for the most part, with the fall of the Romans. During the Middle Ages, few experiments were attempted in water purification or filtration. Devout Catholicism throughout Europe marked this time period, often known as the Dark Ages due to the lack of scientific innovations and experiments. Because of the low level of scientific experimentation, the future for water purification and filtration did not advance.

**MODERN AGES**

**17th century**

Sir Francis Bacon in 1627 discussed desalination in his ‘A Natural History of Ten Centuries’ (Baker & Taras 1981). This was the first record of experimentation in water filtration, after the Dark Ages.

The first known illustrated description of sand filters was published in 1685 by Luc Antonio Porzio, who proposed multiple-filtration through sand, preceded by straining and sedimentation. Porzio’s multiple-filter system (Figure 5) could be placed on land or in the hull of a boat depending on whether surface water or groundwater was to be purified. Three pairs of filters were used for the boat, with each pair consisting of a downward filter and an upward filter.

**18th Century**

In 1746 Joseph Amy of France received the first patent for a water filter that was placed on the market in 1750. Figures 6 and 7 illustrate Amy’s filters. The filter was made of sponge, wool and sand. The Lancashire filter (Figure 8), a crude forerunner of the slow sand filter, was developed around 1790 (Baker & Taras 1981). However, it is the British architect James Peacock who received a patent for a sand filter with backwashing (Figure 9) in 1791. He also published an expository pamphlet that received a lot of attention over the years.

**19th century**

John Gibb developed the first known filter that was used for city-wide supply. This filter (Figure 10) was installed in Paisley, Scotland in 1804. Water was carted to the consumers. The first attempt in the USA for a city to use water filtration
was in 1832 in Richmond, Virginia. A small upward-flow filter of gravel and sand in the water works proved to be a failure for the turbid water of the James River. This was replaced by a downward flow approach which also failed. The filters were too small to handle the highly turbid water.

The evolution of rapid filters (Figure 11) in the USA began with developments by Patrick Clark and John W. Hyatt. Clark suspended a shallow filter in a river and provided surface-jet wash from a perforated revolving arm, with the loosened dirt being swept downstream (Baker & Taras 1981). This filter was installed at Rahway, New Jersey waterworks around 1880. Hyatt superimposed several Clark filters in a closed tank and serviced them with a common pipe system (Baker & Taras 1981). This method was first applied at Somerville & Raritan Water Co., New Jersey in 1882. Figure 12 shows advances in rapid filtration in the USA during the 19th century.

CONCLUSION

This paper has presented a brief history of water filtration and sedimentation practices for potable water management extending from the ancient times to the 19th century. A review has been presented of some of the most important advances in water supply filtration and sedimentation
Figure 7 | Amy’s sextifold filter box for army garrisons. This filter system consisted of three pairs of down-up filters. Water flowed through 5.4 m of sand. The tank was either lead-lined wood or masonry, 5.4 × 0.9 m in plan, and 1.8 m deep. Design closely resembled one described by Porzio (1685) in his book on military camp sanitation (Amy 1754).

Figure 8 | Lancashire filter. This filter was a probably a crude forerunner of the slow sand filter. The earliest versions of these filters were used for industrial water supplies with some of these having been installed before 1790 in Britain (Baker & Taras 1981). (Source: Thomas Graham’s Elements of Chemistry (Graham 1858)).
Figure 10 | Filter system for Paisley, Scotland completed in 1804 by John Gibb. This is the first known filter to supply an entire city according to Baker & Taras (1981). Water flowed through a stone-filled trench to a ring-shaped settling chamber followed by flow through two lateral-flow filters to a central clear-water chamber. Water was then delivered to a tank on the hillside from where it was carted to consumers (from a description in Sinclair’s Code of Health and Longevity, London, 1807; as presented in Baker & Taras (1981)).

Figure 11 | Rapid filtration advances by Clark and Hyatt. (a) Clark suspended shallow filter (from United States patent drawing, June 21, 1881). (b) Hyatt superimposed several Clark filters in a closed tank (from “The multifold water filter”, Engineering News, January 1 (Hyatt 1882)).
practices prior to the 20th century, since the beginning of humankind’s quest for pure water. These have included the practices during the Bronze Age, the Greeks, the Romans, the Middles Ages, and the Modern Ages up to the 20th century.

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