Ancient Hydraulic Systems - Part IV by C. Mundigler

Ancient hydraulic systems came in many varieties, both large-scale and small. Among them were the water-lifting systems of the Egyptians (still in use today), the Archimedean screw used to move water from one level to another, and the extensive Roman use of the water-wheel, all of which we will focus on in a subsequent issue of Labyrinth. It is, however, a lesser known invention of an earlier period which utilized water in a unique way and revolutionized time-keeping, which we will look at in this issue: the clepsydra or water-clock.

Although the ancient people were not overly concerned with daily time except for religious purposes, some "mechanicians" (as the Roman engineer Vitruvius called them) seemed to have enjoyed making improvements, whether functional or decorative, to an early time-keeping device originally invented in the Middle East.

Gnomons, or shadow-clocks, had been in use long before the Romans ever became concerned with time-keeping, but these early shadow-clocks had two serious, and obvious, drawbacks: they were of little use on a cloudy day and completely useless at night! Hence, a small-scale water system was invented which became known as the clepsydra or water-clock. In early Egyptian times, it consisted basically of water and a vessel to contain the water. Later the Greeks and Romans would improve this simple device by adding floats, gears, pointers and graduated scales to the point of extravagance where figures and drums were made to move, cones revolved, pebbles and eggs were made to fall, trumpets blasted and other "incidental effects" took place (Vitruvius, Ten Books on Architecture, IX.8.5). Later still, in the 17th century A.D., Galileo preferred to use the accuracy of the water-clock to time his scientific measurements rather than the inefficient mechanical clocks of the era.

To find the inventors of the clepsydra, however, we must look back more than 3000 years before people like Galileo to the period of around 2000 B.C. in ancient Egypt. The early Egyptian water-clock was merely a stone bowl, in the shape of a truncated cone, with an opening at the bottom which let water run out at a fixed rate. Since the length of days varies with the seasons, the Egyptians marked the inside walls of the bowl with staggered lines and dots to correspond with the three Egyptian seasons. The graduated markings also had to take into account the fact that water pressure in the vessel changed as the volume of water decreased. The flow rate as the bowl emptied would be very different when the vessel was full than when the vessel was almost empty.

Examples of these large, conical stone bowls are in the British Museum in the form of basalt fragments with text on the outside and graduated vertical markings on the inside to compensate the varying length of the days of each month. A beautiful, and fairly complete, conical alabaster clepsydra of the late 18th Dynasty (about 1400 B.C.) from Karnak in Egypt is also at the Cairo Museum, and was displayed at Expo 1986 in Vancouver, B.C.

Later in Egyptian history, the early physicists tried to compensate for the varying water pressure and resultant inaccurate time-keeping by using clepsydrae in a cylindrical form filled from a constant volume reservoir. This improvement made for much more precise readings and was the system eventually adopted by the Greeks and Romans. It was this ancient Egyptian clepsydra system that survived with very little change right down to the Middle Ages when mechanical timepieces refined the accuracy of clocks even further.

Although the Egyptians and Assyrians invented and used clepsydrae centuries before Greeks and Romans, it is the latter who perfected the system and put it to common use. Despite the fact that sundials and shadow-clocks continued to be used by the Greeks and Romans, they soon realized that clepsydrae could be used day or night, rain or shine, indoors or outdoors. Public buildings and private houses alike soon used clepsydrae as much to tell the time as to tell their social status!

In Athens, at the end of the 4th century B.C., a monumental Tower of the Winds was constructed which operated on the same principle as the much smaller Egyptian systems. In this Tower, fed by a spring from the Acropolis, floats sank with the falling water level as the liquid ran out of the Tower at a controlled rate, and a pointer indicated the passing time as the floats fell.

Writing at about 330 B.C., Aristotle gives an interesting account of the use of a water-clock in his Athenian Constitution. In Chapter 67.2, he writes that "there are water-clocks with tubes as outlets: water is poured into these, and speeches in trials must keep to the time thus measured". In this system, the clepsydrae generally consisted of two bowls, each with a hole near the rim to maintain a constant level of water. Different types of trials, both private and public, were allowed different measures of time. Pliny the Younger, a prominent Roman lawyer of the 1st century A.D., indicated that clepsydrae were still in use for timing court trials almost four hundred years after Aristotle described the system: "My speech", says Pliny, "lasted for nearly five hours, for I was allowed four water-clocks in addition to my original twelve of full size..." (Letters, II.11).

Aristotle, in his Poetics (II.7), also wrote that the length of a tragedy should be judged by what is appropriate to the plot, not by the water-clock, "as it is said was once the case in some places". This would indicate that not just court trials, but also drama and literature, came under the influence of the clepsydra!

Perhaps the most valuable ancient source on the construction and principles of the water-clock was the 1st century B.C. Roman architect and engineer Marcus Vitruvius Pollio. In Book IX.8.2 of his Ten Books on Architecture, he describes the ingenious principles and improvements to the water-clock by the innovator Ctesibius of Alexandria, who worked around 270 B.C. Ctesibius is said to have adjusted and improved the way the clepsydra had to be graduated to account for the different seasons of the year and for the varying pressure and flow rates encountered as the depth of the water decreased. He arranged three vessels, one emptying into the other, with constant levels and overflows calculated to ensure that a float, which rose to tell the time in the third and final vessel, would rise to indicate the time accurately. Vitruvius tells us that Ctesibius then attached the float to "a rack and revolving drum, both fitted with teeth at regular intervals" to indicate the appropriate time by pointers, pebbles, eggs or trumpets (IX.8.5). Vitruvius goes on to explain the construction of elaborate mechanisms of drums, chains and counterweights for increasing or decreasing the time of day by seasons, "just as the sun during his passage through the constellations makes the days and hours longer or shorter...." (IX.8.10).

It is obvious that whether for innovation, showmanship or utilitarian reasons, people like Ctesibius of Alexandria, Hero of Alexandria (in the 1st century B.C.), or Herophilus of Alexandria (who counted pulse-beats by a small clepsydra in the 3rd century B.C.), used the very early and ingenious invention of the clepsydra to change forever the way the ancient people looked at time and the way we look at the ancient people.

Next we shall turn out attention from small hydraulic systems to the large-scale systems of water-wheels and water-lifting devices used by pre-Classical and Classical civilization.