Ancient water robotics and Abou-I Iz Al-Jazari

Zekâi Şen

ABSTRACT

Although water resources have been developed throughout the centuries for the service of different civilizations, at different scales and in different regions, their use in automation has been conceived only recently. Research into the history of water from an automation point of view has led to some unknown or hidden facts. Starting from the ancient Greek period before the prophet Christ and after about the 12th century, many researchers tried to make use of water power for working some simple but effective devices for the service of mankind. Among these are the haulage of water from a lower level to a higher elevation by water wheels in order to irrigate agricultural land. Hero during the Hellenistic period and Vitruvius of the Roman Empire were among the first who tried to make use of water power for use in different human activities, such as water haulage, watermills, water clocks, etc. The highlights of these works were achieved by a 12th century Muslim researcher, Abou-I Iz Al-Jazari, who lived in the southeastern part of modern day Turkey. He reviewed all the previous work from different civilizations and then suggested his own designs and devices for the use of water power in automation of excellent types. He even combined animals and water power through early designs of valves, pistons, cylinders and crank mills, as will be explained in this paper. His works were revealed by German historians and engineers in the first quarter of the 19th century. Later, an English engineer translated his book from Arabic into English, revealing the guidelines for modern automation and robotic designs originating from the 12th century. This paper gives a brief summary of the early workers’ devices and Abou-I Iz Al-Jazari’s much more developed designs with his original hand-drawn pictures.

Key words | Al-Jazari, automata, Islam, robotics, technology, water

INTRODUCTION

Throughout history, different civilizations and nations have contributed to technological developments within their prevailing social, religious, philosophical and scientific environments. These points are emphasized by Saliba (2010). The more philosophical enlightenment in a society, the better is the rational thinking and technological contributions. Primitive technological developments, at the heart of the historical origins of man, can be identified through the single body of information that lies in the vast body of excavation reports prepared by numerous archaeologists. One has to rely on fragments of pieces unearthed during careful excavations. Another source of information lies in the pictures drawn by artists in antiquity. These may be widely differing kinds, such as wall paintings, mosaic pavements or pictures painted on pottery. There are many pictures of Mesopotamian monarchs hunting lions and conducting military campaigns but, unfortunately for the humbler crafts, there is an extraordinary blank (Hodges 1970). These are concerned mainly with the period of history prior to the invention of scripts. The technological developments on larger scales have been detailed by successive civilizations and there are written documents. At one extreme, lie the very early clay tablets on which the scribes kept accounts for their masters, and, at the other, the writings of the Greek, Roman and Muslim men of science that have been handed down to us. For the development of

doi: 10.2166/ws.2013.031
modern technology, clay tablets cannot be regarded as a reservoir of information, because most often they include items such as the number of slaves used in a certain operation, laws that govern society and perhaps the writs of rulers for different purposes.

As the ability to read and to write became more widespread, so more and more records became available that are pertinent to technological subjects, until there finally emerged what can best be called workshop recipes, often quite detailed, giving, for example, the formulation of a particular glass, stating not only the materials to be used but also the processes to be followed. Such sources of information accumulated through the years and provided a common basis for those who would like to pursue further advancement towards better technological horizons. Unfortunately, in the past, since communication facilities were not fast and sufficient enough; most of these written documents did not spread but remained on the shelves for many centuries. One question to ask is whether mankind could have improved technological gadgets earlier in history, had such information been connected in the sequence of time. It is obvious from the discussion in this paper that such a continuous process in technological evolution has not taken place in different parts of the world. Recent studies indicate that some technologies, which supposedly originated in a certain location, culture and time, were developed in other foreign societies many centuries ago. Hodges (1970) has reported in detail various technological developments in different parts of the western world, but he has ignored the vast majority of eastern development towards technology. Another point raised in his book is that anything that did not fit with western society was included under the label of the barbarians. Although the Islamic technologies have also been included as a subset of barbarian technology by Hodges, this paper will erase such an unjustifiable allegation with the ingenious mechanical devices, which predated the western industrial revolution by at least five centuries. The first works in the West concerning Al-Jazari were initially reported by Wiedemann & Hauser (1915) and Hauser (1922).

Most of these documents have not been well identified, especially in Islamic civilization, which shed light on classical Greek civilization with an introduction to the western Renaissance in many aspects. In this paper, the forgotten masterpieces of Muslim technological devices will be illustrated through Al-Jazari’s hand-drawn mechanical systems. He pioneered many modern technological concepts but, unfortunately, due to a lack of communication, his studies and mechanical devices were not well recognized until the work by Hill (1974). Thereafter, many other scholars have studied Al-Jazari’s ingenious water devices from different aspects (Sarton 1950; Al-Hassan 1977; Şen 2000; Alertz 2010; Romdhane & Zeghloul 2010).

**HISTORICAL PERSPECTIVE**

In western culture, freedom of thought from the pressures of the church and the development of scientific knowledge have been based on the ancient Greek activities. It must be remembered right at this point that the Muslim scholars in north Africa, and especially, in Muslim Spain (Andalusia) contributed a flow of information and consequent enlightenment in Europe from the 10th century which endured for more or less 5 centuries. During this period even the original classical Greek books and documents by Plato, Aristotle and others were translated not directly from the Greek language but from Arabic, because at that time, the language of scientific thought in eastern and especially Islamic countries was Arabic. The point was documented by the pioneering scientific historian Sarton (1950), that from the 7th to 13th century there is not even a single western thinker, philosopher or scientist’s name recorded as opposed to the many in the Islamic world.

Abou-l Iz Al-Jazari, who lived during the 12th century, is the father of robotics, which worked by water power hydraulically. He reviewed the work of previous technological developers such as Vitruvius and Hero who lived in the first few centuries after the prophet Christ in the Roman domains. They did not leave proper designs or procedures for their few original technological ideas, but Abou-l Iz Al-Jazari drew many mechanically proper designs in his hand-written book which was printed in its original form by the Cultural Ministry of Turkey (1990). His book has been translated into English by Hill (1974) with the modern drawings corresponding to the original ones by Al-Jazari. He lived in the southeastern part of Turkey under the Turkish dynasty of Arthuque Turks, which reigned...
during the 12th century in the region of Diyarbakır, which is the greatest city presently in southeastern Turkey. A glance through his book brings to one’s mind the question of who was the first man in human history to visualize and draw mechanically usable devices that compare most closely to today’s technological level? Perhaps, most of us will jump to the conclusion that it will be, if during ancient history, somebody from the ancient Greek period or if more recently after the Renaissance, someone from a European country. Such automatic thinking will lead to error, and the true and provable answer is Abou-l Iz Al-Jazari who lived during the medieval period. It is important to emphasize at this point that the medieval period was indeed a time of enlightenment for Islamic countries, whereas Europe was living in the dark ages. Due to cultural erosion, even today in Islamic countries, many will find it hard to believe that a Muslim technologist devised automatic robots in the 12th century. This is due to the fact that Muslims do not look to their prosperous past but automatically get their records from other sources, most of which may not reflect the reality.

Europe has been in direct conflict and has been mixing with eastern countries, among which the majority were Muslim societies that even reached Spain, and consequently, information sources from these societies entered the West during many centuries. It is not possible to think that the Renaissance came into existence without friction with Muslim countries, who had translated, criticized, and improved all the eastern and ancient Greek philosophies and ways of thinking into Arabic and spread these ideas among their scholars. One of the lessons that can be drawn from this discussion is that science and technology require as fertilizers the social, economic and religious status of the society. The more accessible these fertilizers, the more science and technology shift towards these centers. The books of many Muslim thinkers have been translated first into Latin then into various other languages, and, consequently, the public of the countries concerned have started to understand the basic information and the establishment of this information between scholars of the country, giving rise to enlightenment for future generations and developments. For this reason, it is necessary to deal with scientific and technological history with emphasis on the countries’ perspectives in the past.

Scientific historians have sought more narrowly to find the sources of scientific rationality in the arts and crafts, that is, in the prevailing technology and artisanry (Weber 1951). The science and its consequent technology have undeniable civilizational dimensions as outgoing social activities. Hence, it is neither ethnocentric nor orientalist to speak of the directive structures and institutions that served as the guiding moral, religious, and legal frameworks for intellectuals in medieval Islamic civilization, in China, or in Western Europe (Huff 1993). During the medieval period, symbolic and intellectual discourse was relatively institutionalized and shared to a great extent by informed individuals living in widely scattered locations across all the then existing civilizations. Hence, it is not objective scientifically to state that modern science and technology were products of a single civilization but were an inter-civilization outcome.

ISLAMIC TECHNOLOGY BEFORE AL-JAZARI

First it can be said that the contributions of Islamic civilization to the West shaped the development of modern science, because this civilization was intermingled with the elements of previous civilizations’ thoughts, philosophies, and documents through translations into Arabic which were conveyed to the West. Among the intermingling civilizations were China, India, Persia, and ancient Greece.

Unnamed Egyptian engineers around 300 BC presented some of the earlier examples of simplistic technological gadgets. During the Roman era, Vitruvius claimed that an early primitive water clock was invented by the Egyptians. Ifrah (2001) stated that among early technologies was a four-wheeled chariot, eight cubits broad, drawn by 60 men, and on which was seated a statuette of Nysa measuring eight cubits, dressed in a yellow, gold-brocade tunic and a Spartan cloak. This mechanism helped her to stand up unaided, pour out milk from a golden bottle, and sit down again. In 230 BC Philo from Byzantium made some contributions towards automation and his ideas existed in a number of Arabic writings. He described a variety of automata and complicated vessels that exemplified early water technology. Muslims have translated important works of previous thinkers into Arabic. For instance, the text by Archimedes ‘On the
Construction of Water Clocks’ is among such translations. This text was partially written by Archimedes with later additions by Islamic scholars. In particular, instrumental parts and their principles were systematically developed by Islamic engineers, such as water-mediated control and power generation. During the first century CE, Hero of Alexandria was well and widely known for his early technological explanations. His works are collected in the text entitled ‘Pneumatica and Automata’ in which he expounds on the fundamentals of pneumatics and plans for a variety of machines and automata that are driven by pneumatic forces.

In order to convey limited underground water in deserts or arid regions, the Persians developed the qanat system for transferring water over long distances for drinking and agricultural purposes. Qanats transfer underground water to the surface from the aquifers of mountainous or flat regions through one or more man-made tunnels. Water flows inside the tunnels with a gentle slope that provides the gravitational flow of underground water (Mostafaeipour 2010). Especially, prior to the 13th and 14th centuries, the contribution of Islamic civilization to the foundation of knowledge, logic, mathematics, astronomy, and methodology were very significant. Some would say that it was the Greek heritage of intellectual thought, above all its commitment to rational dialogue and decision making through logic and argument, that set the course for intellectual development in the West (Needham 1954). One does not have to subscribe to such a view in order to recognize the great importance of the Greek tradition to western science. The more important point is, however, that modern science is the end product of several such sustained inter-civilizational encounters over the centuries (Huff 1993). A detailed account of water, both historical and modern, is presented by Tempelhoff et al. (2009).

Khawarizmi (Algorithm in Latin) wrote a book entitled ‘Mafatih Al-Ulum’ (Keys of Sciences) during 971–991, and in this book he reported on various automatic devices that were used by Muslims up to that time. Some sections and paragraphs include mechanical devices or their elements as knowledge. This book includes explicitly all the terminology that was used by Al-Jazari. Another Muslim scholar whose ideas influenced Al-Jazari was Fakhreddin Radwan bin Mohammad Al-Sa‘a‘i. Although Radwan was a physician, he was also interested in literature, logic, and philosophy. His interest in technical aspects was lacking, which is apparent from his technical drawings. However, even though his drawings were incomplete, they were a stimulating source for further Muslim technological developments. Since he was not a technical man, his drawings were not detailed.

During the reign of Abbads in Bagdat, vicegerents urged the translation of information, knowledge, philosophical, and engineering books into Arabic and they even established a house of wisdom titled ‘Bayt-ul-Hikmah’ for this purpose. The aim was to provide to Muslim scholars the previous works of different civilizations so that their society could prosper and become wealthy. Among these translations were the works of Philon of the Byzantine period who lived during the 2nd century CE and wrote a manual titled ‘Phenomatics’, in addition to the work of Hero of Alexandria. These two men did some work on automatic objects but did not leave detailed documentation. Their work consisted of fragmentary remnants without clear inter-relationships between the pieces, nor were there any drawings. During the translation period even the works of Archimedes were translated into Arabic and these were mentioned in Al-Jazari’s work, especially in the cases of water clocks. Al-Jazari knew the works of Archimedes, Philon, and Hero, and Muslim researchers and he benefited from their enlightenment.

Prior to Al-Jazari, there were several Muslim thinkers who gave rise to technological ideas and devices, among whom were the Banu Musa brothers, Khwarizmi and Radwan. Banu Musa was a collective name for the three brothers Abo Cafar Mohammad, Abo Qasam, and Hassan. After their father’s death they were protected by the Abbads vicegerent Al-Ma’mun. The devices produced by these brothers were later modified and used by Al-Jazari. Among the works of these brothers were about 100 different devices, seven of these were fountains, four automatic crimping machines, an automatic musical instrument, a gas mask for approaching polluted water wells, and the remainder being water reservoirs of various shapes and sizes. The brothers also considered whatever was available to them from previous researchers, especially Philo and Hero, although Banu Musa produced more sophisticated and automatic devices than these men.

Modern technology has been assumed almost worldwide to be a product of western civilization only.
However, long before western civilization, other civilizations, such as the ancient Egyptians, Mesopotamians in practical works, and the Muslims with ingenious devices of wisdom, had contributed to the development of modern technology. At least, it is historically evident that such contributions are now appreciated to an equitable extent. Hill (1974) reported that the great Italian engineer, Juanello Turriano, who worked and wrote in the 16th century in Toledo, Spain, would have been able to inspect the hydraulic works of his Muslim predecessors and draw upon the long tradition of Muslim water engineering. It is, therefore, possible to assume Muslim influence on his achievements, although there is no written record to confirm this. Many Muslim ideas eventually found their way into the general vocabulary of European engineering. It can be justified in believing that most of these were not reinventions, which are rare events in the history of technology, but had been received, directly or indirectly, from Muslims. In particular, Abou-l Iz Al-Jazari’s work on hand-drawn mechanical devices provided visual and intellectual recipes for further development of the technology.

During the medieval period many authors in the West agreed that the Muslims were advanced in modern scientific subjects, such as logic, philosophy, mathematics, optics, algebra, chemistry, medicine, and astronomy. Technological developments pursued rather an independent path from philosophical ideas and sought practical functions. Among these were windmills, waterwheels, sailboats, powder and fireworks, etc. During the medieval Islamic period, the best of the technological developments were gathered together in a book by Al-Jazari, ‘Kitab fi ma’rifat al-hiyal al-handasiyya’ which was translated by Hill (1974) as ‘The Book of Knowledge of Ingenious Mechanical Devices’. Hill stressed that of all the fields in which Muslims have made significant contributions to the progress of civilization, that of mechanical technology has been the least studied. Technology has flourished whenever and wherever conditions were favorable. In particular, technology has been relatively fettered by ideologies, and, therefore, found its way as a diffusion of ideas in different aspects of practical life. So far in time, technological developments have not followed a steadily increasing trend of knowledge but rather there were sudden leaps irrespective of geographical and political separations. Technological knowledge was transferred to future generations via the written word and, in very rare cases, through drawings. Al-Jazari’s work is exceptional in this case, especially when it is considered that many did not care to commit their devices to paper, because his book not only includes detailed drawings but also explanation of the devices’ working mechanisms. Mechanical arts flourished in the Islamic world between the 9th and 15th centuries. This may be due to an accumulation of verbal information transmission from previous civilizations in the Middle East and the Near East. Among these civilizations, ancient Egyptians, Greeks, Romans and Byzantines have achieved in various ways small-scale technological advancements. In the meantime, technological information from Persia, India, and the Far East participated in development, but Islamic technology was based mainly on ideas from eastern Mediterranean civilizations. Muslims did not imitate the technological devices of the past, unless they were in use, but rather developed original devices, which were the products of Muslim scholars such as Al-Jazari. The driving forces behind the Islamic technological development were twofold: on the one hand, the daily practical necessities such as water and windmills (energy), especially water-raising devices, and war machines, and on the other hand, devices that created wonder and aesthetic pleasure in people. Even at this juncture, there were written documents for creating pleasing devices, but very few for devices for everyday use. It is known that Al-Jazari did not hide his technological findings from others as he constructed and used them in front of people and, more importantly, he wrote and drew them in the form of a book.

TECHNOLOGY AND AL-JAZARI

Hill (1974) gave a detailed account about the technological development in the Islamic world before Al-Jazari. Al-Jazari’s book is regarded as being a technological accumulation of the Islamic period. Sarton (1950) wrote that Muslims reached the peak of technological accumulations in the work of Al-Jazari. Basic information about him is given in the introductory section of his book entitled ‘Kitab fi ma’rifat al-hiyal al-handasiyya’. Al-Jazari implemented all the existing and experimental works in his original designs of mechanical devices, although
calculations were not available at that time. He used numbers in order to describe certain quantities, but various parts of his devices were obtained in proportionate harmony with other elements of the device after a long period of trial and error. However, in the works of Muslim engineers, the remnants from the Hellenistic period in the Eastern Mediterranean were efficient. Nasr (1964) mentioned the studies of Islamic technological, philosophical, and natural views. The first and by far most significant study of Al-Jazari’s biography was described by Wiedemann & Hauser (1915). Al-Jazari completed Archimedes’s missing elements and produced the first completely working water clock with all its elements as well as their explanation in great detail. Another mechanical element developed by Muslim researchers is the conic valve that had not been designed by any previous civilization. The conic valve was used in many different parts of devices in Al-Jazari’s book.

Al-Jazari devised instruments for humanity about 800 years ago, but unfortunately, his workings were not unveiled until the previous century. In short, his work may be considered as the essence of cybernetics, robotics, and automation of mechanical devices. He expressed his ideas, opinions, and views not in a subjective manner as many ancient Greek philosophers have done, but on objective grounds with drawings that can be understood by everyone, even today. It appears that the engineering aspect of his character was more significant than the philosophical and scientific aspects.

Al-Jazari is one of the scholars trained during the era of the Arthuque Turks. He was supported by the then ruler for his robotic devices, and was asked by him to collect all the devices in the form of a book with picturesque illustrations. He applied his ingenious devices in front of the people and gained their appreciation. Looking at his hand-drawn mechanical devices and their comparison with present-day robotics gives us a first glimpse that he designed machines that worked by water power and are comparable with present-day drawings. His drawings gave rise to servomechanical ideas and, consequently, cybernetics, which, as a branch of science, emerged during the previous century. His ideas and drawings provided intuitive opinions towards mechanization in the 19th century.

Automata are the immediate ancestors of the elaborate water clocks of Europe and worked with water power mechanically. Some historians of technology have expressed dissatisfaction because so much of the ingenuity of the Muslim engineers was directed to the design and construction of such apparently trivial devices as automata, rather than to the production of useful machines. This view is quite erroneous, however, not only because it neglects the existence of a utilitarian tradition that was not recorded in writing, but also because it fails to consider the contribution made by the makers of hiyal to the advancement of machine technology (Hill 1974). The making of automata in ancient Greece, in Islamic countries, and later in Europe was one of the factors that led men to develop a rationalistic and mechanistic explanation of natural phenomena, an attitude that has been immensely fruitful in the development of modern science. It was Al-Jazari’s monumental clock, however, that displayed the most impressive display of automata. The automata were activated by a float sinking at a constant rate in a water reservoir. A string attached to the top of the float passed around a large pulley wheel that was the main drive of the clock. Through other pulleys it rotated the zodiac circle and drew along, behind the face of the clock, a small wheeled vehicle to which was fixed a vertical rod that operated the tripping mechanism. The success of water clocks is directly dependent on the achievement of a constant rate of water discharge. Al-Jazari located a vertical, conical valve seat at the end of the outlet tap from the reservoir. Beneath this valve seat was a small float chamber, with the conical valve plug fixed to the top of the float. The outlet pipe was soldered to the lower end of the float chamber. When the top was opened, water ran into the float chamber and the valve closed momentarily, only to reopen when water was discharged from the float chamber. The cycle repeated itself until the water in the reservoir was exhausted.

**AL-JAZARI’S WORKS**

Early Muslim technology had two separate aims: namely, ingenuity, aestheticism, and the admiration of the people on the one hand, and daily practical usage for services among which were water mills, water-raising, war-machines, etc. The achievements of Muslims might be considered to have three main driving forces. During the Muslim reign, the Banu Musa brothers worked on automata (hiyal).
including many devices. Later in 1203, Ridwan bin as-Sa’ati wrote a lengthy treatise dealing with the repair of a monumental water clock built by his father over the Jayrun gate in Damascus. Finally, in a concise and substantial work in 1206, Al-Jazari described the best mechanical devices that he had invented and designed during his long life. Al-Jazari’s work is superior to all previous work and, unfortunately, his work was the last of the best of Muslim technology. The Greek and Roman eras created an unbroken tradition of mechanical manufacturing. Fortunately, interest in a more formal application of mechanics and hydrostatics arose during the time of the great Abbasid caliphs in the 9th century. With these achievements, some preliminary Greek treatises were translated into Arabic, notable among these translations are the Pneumatics of Philo of Byzantium and the Mechanics of Hero of Alexandria. Muslims needed to have at their command all the contemporary scientific and technical skills available in order to obtain the best possible results from the limited resources at their disposal. Practical descriptions of construction provided by Al-Jazari were very convincing. Muslim engineers sought deliberately that their devices should genuinely work and they gave considerable thought, not only to achieving the required results, but also to ensuring that the finished machines would be easy to operate and maintain. Additionally, there were elegant aesthetic motivations in the inventions, in providing solutions to engineering problems. It is certain that Muslim technology was essentially based on the use of the effects of water pressure without an understanding of the mathematical relationships of the underlying phenomena. Their practical skills and knowledge were combined together with energy and patience to reach the best of solutions. The harmony between different parts of any technological device was obtained through patient empirical rule of thumb and trial and error methodology. Hence, it become an art that could not transferred to later generations by symbolism or mathematics but only through plain writing. Unfortunately, such writings did not include every detailed piece of information, and consequently, since the technological devices were not put into steady practical use, the basic knowledge that had been obtained with hardship and labor were easily forgotten. It is not possible even today to easily redesign Al-Jazari’s original opinions from his writings without implementing personal knowledge, interpretation, or clarity. Although Al-Jazari knew that the flow of water through any orifice in his design was proportional with the hydraulic head, he did not know the mathematical relationship as we know it today. In the mathematical relationship, the rate of flow $Q$ is related to the square-root of the head, $h$, through an orifice constant, $K$, as $Q = K\sqrt{h}$. Of course, the orifice constant is proportional to the orifice diameter. Hence, Al-Jazari manufactured different orifices with different diameters and by using them in a sequence and with a trial and error approach, he found the most convenient orifice for his technological mechanical water device. In this manner, he was using the experimental scientific approach, since at that time, it was not common to seek a mathematical formulation that would relate the variable of interest or control to causal variables. In fact, in this manner, Al-Jazari experimentally approached the underlying and, at that time, unknown equations with technologically successive trials. This provided him with the experience of the appreciation of orifice diameter in the case of any hydraulic head. In his approach, first he produced a narrow orifice and then a succession of orifices with increasing diameters ready for use at any time. It may be that his studies were among the most laborious in Muslim technological achievements. This gave him a clear understanding of arithmetics, plane geometry, measurement and appreciation of relationships in the construction and assembly of his devices.

Among the early water mills were the machines used for raising water and these played an important role in the economy of Middle Eastern countries (then all Islamic states) for many years, mainly, for irrigation and agriculture. These wheels were necessary instruments for supplying water to communities. The very early type of these is referred to as *shaduf* in Arabic and is still in use in some Middle Eastern countries such as Syria. It consists of a long pole balanced on a fulcrum with a bucket on one end and a counterweight on the other. A more complicated water wheel includes a series of pots on the circumference and this is known in Arabic as *saqiyyah*.

Many full-scale machines were described by Al-Jazari in order to raise water and all of them incorporated features that are of great significance in the history of machine technology; even today some of these parts are in common use in any machine design. The first of these is presented in
Figure 1 where water power is used to raise the left and right hands of a robotic man on an elephant. Water injection from the right nozzle hits the left of the scoop at the back of the elephant and hence, the left hand of the robotic man is raised. This is the first, most simple design towards robotic studies in the history of technology.

Another example is presented in Figure 2, where animal power is used to raise a flume-beam sweep, that is, a wooden channel with a large scoop at one end and a fulcrum at the other. The scoop is dipped into a water well, and when the scoop is raised above the fulcrum, the water runs along the channel and then discharges into the irrigation system. Power is transmitted by a donkey tethered to a vertical axle, which rotates as the donkey walks around in a circle. The axle, through a pair of gear wheels, rotates a horizontal axle upon which is mounted a wheel with teeth on a quarter of its circumference. This wheel meshes with a lantern pinion located on the horizontal axle upon which the sweep pivots. While the donkey circles, the sweep rises and falls as the segmental gear wheel engages with and disengages from the lantern pinion. This machine is shown in Figure 3 and is a refinement of that in Figure 2.

This machine consisted of four sweeps, segmental gear wheels, lantern pinion, which quadrupled the output. A further improvement, according to Al-Jazari, was the smoother operation obtained by reducing out-of-balance forces.

In his third machine there is also a flume-beam sweep, and again it is powered by a donkey walking in a circular path. In this machine, the end of a crank driven through a system of gears, enters a long slot beneath the channel of the sweep. As the crank turns, the sweep rises and falls. Although cranks had been in use for centuries in hand mills and on contrivances such as winches and capstans, they were in all cases operated by hand (Hill 1974). As shown in Figure 4, Al-Jazari’s machine provided the first example of a crank being incorporated in a machine.

Another machine as shown in Figure 5 is of little importance, being simply a chain of pots driven by a concealed scoop wheel. It was intended for use in near or ornamental pools.

Al-Jazari’s most interesting machine, however, with its significance for present-day technology, is shown in Figure 6. This machine had a significant place in the development of the steam engine and pumping machinery.
This system benefits from wind energy that is turned into mechanical energy through the panels located radially around a horizontal axle. On the same axle is mounted a toothed wheel that transmits the rotational movement into another wheel. Towards the outer rim of this wheel is a peg which is fixed normally to the surface. This peg enters a slot rod, the lower end of which is pivoted at the bottom of the box. With the turning of this wheel, the peg moves up and down in the slot, and consequently, the rod oscillates from right to left. Another two rods are attached by ring-and-staple fittings to the sides of the slot rod, and to the end of each of these a piston is attached. These are manufactured from two circular copper disks with hemp packed between them. The pistons move inside the horizontal cylinders. Each one of the pistons is provided with a suction pipe that descends into the water. The delivery pipes are reduced in diameter shortly after they leave the pistons and they are connected together to form a single delivery exit. As the slot rod oscillates, one piston is on its delivery stroke with the other on the suction stroke. The pump, which works on the double-acting principle, is a notable early example of the conversion of rotary to reciprocating action and is also remarkable for having a true suction pipe, albeit rather a short one.

CONCLUSIONS

Technology has evolved quite independently from philosophical ideas and scientific theorems, especially in early civilizations. Humans needed shelter, protection from wild animals and the weather conditions, in addition to food for their survival, and hence, tried to care for themselves against natural phenomena in a safe manner. Different civilizations, including those of China, India, Mesopotamia, Egypt, ancient Greece, Islamic countries and the West have participated in the evolution of technologies throughout history. Primitive technological developments at the roots of the historical origins of man can be identified through the single body of information which lies in the vast body of excavation reports prepared by numerous archaeologists. Technological developments on larger scales have been elaborated by successive civilizations and there are written documents. Most of these documents have not been well identified, especially in Islamic
civilization, which shed light on classical Greek civilization with introduction to the West's Renaissance in many aspects.

Al-Jazari, who lived during the 12th century, is the father of robotics that worked by water power hydraulically. He reviewed previous technology developers such as Vitruvius and Hero who lived in the first few centuries after Christ. Unfortunately, they did not leave proper designs or procedures for the few technological ideas they originated, but Al-Jazari drew many mechanically correct designs in his hand-written book which was printed in its original form by the Cultural Ministry of Turkey (1990). The main purpose of this paper is to report the development of technological devices prior to Al-Jazari and then his original contributions are presented in the form of several mechanical working devices which were used for water haulage and depend on water power.

Such vast experience could only be transmitted through apprenticeship to other individuals. Had it been that the Muslims regarded Al-Jazari’s works with the intention of implementing them, it would have meant a breakthrough in the history of technology for arriving at today’s modern automatic devices a long time ago. Unfortunately, Muslim science and technology were very individualistic and little protected by the authorities, other than the admiration of higher authorities. These ideas were not commonplace to the people and younger generations. Consequently, after the death of Al-Jazari, his works went unnoticed. However, in technological developments, continuous regard and concern are necessary to achieve better devices. In particular, if a technical device is complex and delicate, then its assembly and adjustment require painstaking trial and error which was the case in Al-Jazari’s works. Ignorance of continuity and, unfortunately, individuality have hampered the development of Muslim technology and science alike, but left vast initial and boundless conditional knowledge and technology for further developments to other European civilizations after the Islamic medieval period. It is, therefore, necessary to emphasize at this point that although the medieval period was a dark age for Europe, it was a period of enlightenment for Muslims, since during this period, Muslims achieved an excellency of science via inheritance from previous non-Muslim civilizations and by augmenting knowledge and scientific principles. Unfortunately, Muslims were not aware of their very rich and prosperous cultural heritage until recently, and the works of Al-Jazari have been buried unnoticed in history.

The works of Al-Jazari are very advanced for the era in which he lived (as his hand-made drawings witness). It may be that some history researcher can prove/discover that the scientific advancements of Muslims passed in some way to western scientists, likely in the Renaissance period by means of commercial relationships between the eastern and western parts of the Mediterranean sea, which then became the base for studying the most famous modern scientists such as Leonardo da Vinci, Torricelli, etc.

REFERENCES


First received 20 June 2012; accepted in revised form 24 September 2012