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Paper

HIGH PRESSURE PUMPS & SYSTEMS

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ABSTRACT

This paper discusses the development of pumps, water jetting systems and the high-pressure technology that is being used in almost every industrial endeavor. High pressure pumps and Ultra-High pressure equipment is used in Aerospace Industry, Petrochemical related fields, material testing, coating removal and the cutting of many materials. The resent experience, case studies and research may help engineers, scientist and end users to understand the technical side of the pumps, nozzles and accessories that have been developed for special applications. A review of some high pressure systems using water jetting and high pressure pumps is included to encourage more uses for the technology so the water jetting industry will continue to grow in the future.

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1.0 INTRODUCTION

A reciprocating pump has been defined as a mechanical device used to impart a pulsating dynamic flow to a liquid and consists of one or more single or double acting positive displacement elements (pistons or plungers). The definition goes on to say that the pistons or plungers are driven in a more or less harmonic motion by a rotating crank with a connecting rod arrangement. This motion generates flow by pulling the fluid through inlet check valves and pushes the fluid through outlet check valves that are located near the inlet and outlet of the pump. Some people have written that pumps are devices for exerting pressure upon fluids for transportation or through them to transmit pressure to a more or less remote point where it is transformed into work. In the case of positive displacement, high pressure, piston or plunger pumps, it could be said that they create flow (not pressure) until the flow is restricted which causes the pressure to increase in the fluid. As long as there have been people, there was a need to move water from one place to another. Cupped hands gave way to clay vessels, wooden buckets and aqueducts to provide water to remote locations.

2.0 EARLY HISTORY OF PUMPS

The earliest mechanical device of authentic record for lifting water was the "Shadoff" that was used by the Egyptians as early as 1500 B.C. for watering their herds and irrigating farmland. The Shadoff consists of a counterweighted, pivoted pole with a rope and bucket, which the operator uses, to his advantage to draw water from the Nile River. See Figure 1.

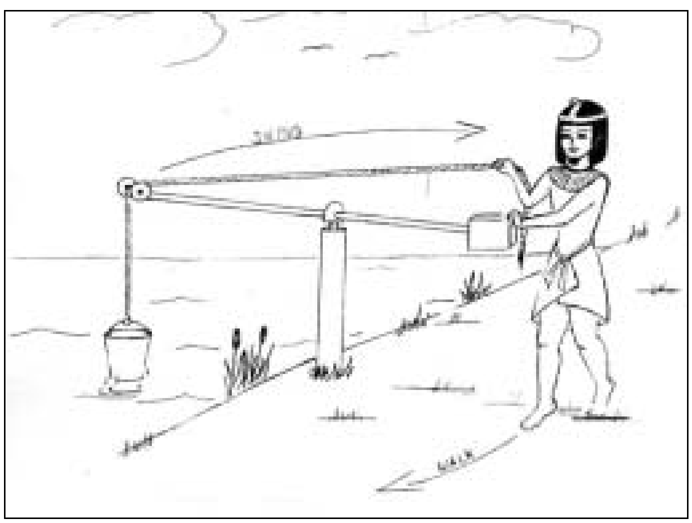

Figure 1 – Egyptian Shadoff

This type of device was used on The Amazing Race television show that aired August 14, 2004 when the contestants had to draw water from the Nile and fill a 1 liter jar, then ride a donkey across the fields to a village where they filled a two liter clay pot. It took at least two trips to accomplish the task so a villager could give them an envelope with directions to their next destination. The Chinese may have made the next improvement by attaching buckets at intervals to a loop of rope over a windless that could be turned by hand or treadmill as indicated in Figure 2. This enabled them to move water from a river into the rice fields for irrigation. About the beginning of the Christian era, the Romans extended the rotary principle by attaching buckets to a large wheel to dip the buckets into the water then lift them up and over the wheel to be dumped into aqueducts as portrayed in Figure 3.

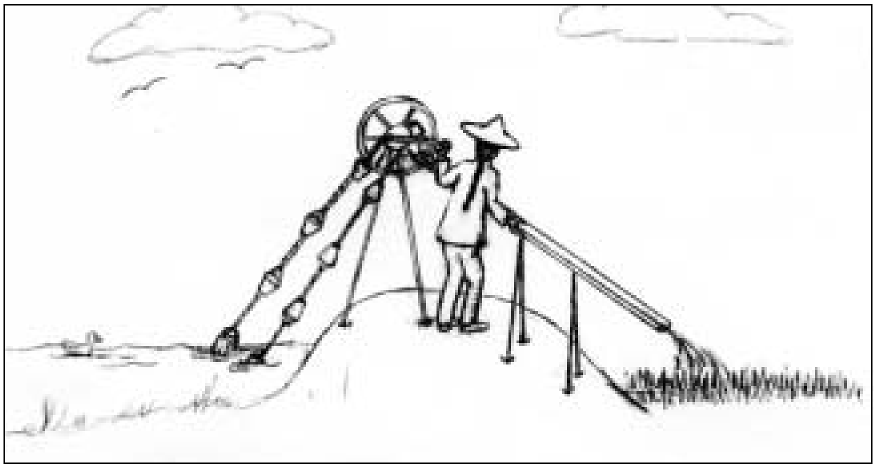

Figure 2 - Chinese continuous bucket rope

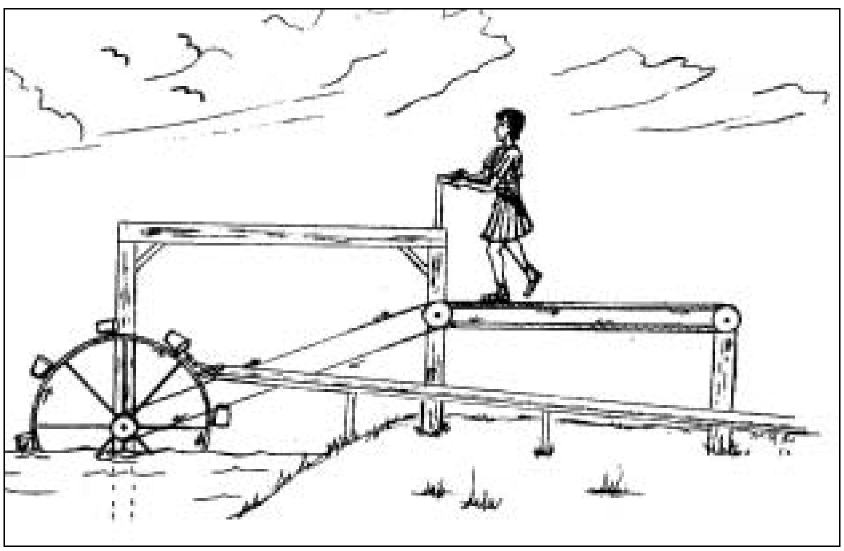

Figure 3 - Roman bucket wheel

3.0 THE FORCE PUMP

A Greek mechanic named Ctesibius is believed to be the inventor of the force pump. The pump had two vertical cylinders mounted side by side with single-acting pistons. A walking beam actuated these pistons so that the pumps gave a practically continuous stream. A device called the Ram Pump is being manufactured by Weatherford to handle multiphase oil products and is powered by hydraulic cylinders as shown in Figure 4.

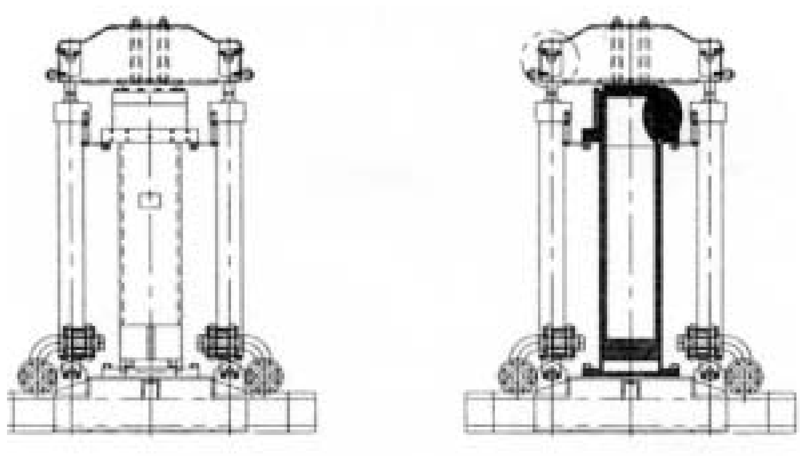

Figure 4 - Ram Pump

4.0 THE SCREW PUMP

The screw principle of raising water is generally credited to another Greek named Archimedes. The origin of modern pumping equipment can be traced to his ancient designs. Giambattista Della Porta is credited with suggesting the use of steam acting directly on the surface of the water in 1601. The cost and physical limitations of de-watering mines with animal powered pumps inspired the use of steam, but it was too wasteful for that purpose. The steam condensed before it had done its work, so in 1707 a French scientist residing in Germany named Denis Papin proposed separating the steam and water by a piston. It reduced the condensation and provided a pocket in the piston that could be preheated by inserting a hot iron block before the steam was applied. In America, Henry R. Worthington invented the first direct acting, reciprocating steam pump in 1840, which widened the field of steam pumping applications. Prior to this invention there were no small steam pumps so the new design was originally used in Erie Canal steamboats until this type of boat was no longer used. The pumps were then removed from the boats and used for another 30 years for other purposes.

5.0 THE CENTRIFUGAL PUMP

The first known use of centrifugal force to pump liquid was designed by Johann Jordan in 1680 and the first pump that resembled the present centrifugal pump was designed in 1818 by an unknown inventor. It is called the Boston or Massachusetts pump, so that must be its birthplace. The rotary pump design also traces it history back to the gear & lobed type found in a collection made by a Frenchman named Serviere who was born in 1593. The sliding van type rotary pump was described by an Italian named Agostino Ramelli in a book that was published in 1588 while the screw type rotary pump can be traced to the Greek named Archimedes. In more modern times, Adolph Wahle of Davenport, Iowa patented the turbine or regenerative pump in 1915. Steam pumps may still be in use today, but have become secondary to the power driven pumps because of the efficiency of a direct acting pump and the various means of driving them. Power can be provided by electric motor or engine and be connected by a belt drive, chain drive or gear box. The pump unit can be portable when engine driven or be powered by electricity over great distances for a wide field of applications. The history of high-pressure pumps continues in several countries and often involves interesting needs and individuals.

6.0 THE PLUNGER PUMP

Sir Samuel Moreland invented the plunger type pump in 1675. While the piston (with a leather seal) in a cylinder had been used before the Christian era, Moreland’s pump may have been the first use of a piston rod and stuffing box (packing in a cylinder) to displace water. The history of high pressure, positive displacement pumps in the United States of America is closely tied to the oil industry. Whether it is a power driven, double acting, reciprocating pump used in the oil fields or the high pressure water jetting pumps used for Petrochemical cleaning, cutting and surface preparation, they came from and are used in connection to the oil industry. The early models were found in crude oil gathering, artificial lift, pipeline applications, drilling mud, refined products and salt-water disposal. The materials have improved the valve & packing design has improved, they come in vertical & horizontal models, but the modern day pump continues to develop to provide efficiency and dependability for pumping fluids at high pressure.

7.0 PUMP DEFINITION

Positive displacement, reciprocating pumps can be classified as power pumps or direct acting pumps; horizontal or vertical pumps; single acting or double acting pumps, piston, plunger or diaphragm pumps; simplex, duplex or multiplex pumps. In the high pressure and ultra high-pressure fields, intensifiers and plunger pumps are most often used to provide pressures in the 10,000 to 40,000 psi ranges. A reciprocating pump is a positive displacement and not a kinetic machine like a centrifugal pump so it does not require velocity to achieve pressure. It is an advantage to obtain high pressure at low velocity for large flows and slurry applications. A reciprocating pump has high efficiencies in the range of 85% to 94% with a 10% loss through belts, gears, bearings, packing and valves.

Flow capacity is a function of pump speed and displacement and relatively independent of pressure but can only move fluid if the suction supply delivers fluid to the pump. It has been said that a pump cannot suck liquid into itself because there is no tensile strength to the fluid, but it can remove the air from the pump cavity, which creates a partial vacuum to allow the pump chambers to fill.

8.0 HIGH PRESSURE PUMP SYSTEMS

Systems that include a high-pressure pump have become an important part of product manufacturing, material processing, fluid conveying and plant maintenance. Around 1947, a cleaning system consisted of a hand held wand or lance that operated at pressures in the 400-500 psi range. The high-pressure water blast gun had its origins in the 1950's and has been re-designed and improved ever since. In the 1960's some steel mills used high pressure pumps with fixed nozzles to de-scale billets and slabs of red hot steel. Automated systems were developed to handle 10,000 psi for de-scaling forgings using rotating jets, manipulating equipment and water recycling. The development of automated systems may have started in the 1950's to 1960's, but it progressed rapidly through the 1970's to 1980's. Mechanical devices can handle larger horsepower pumps with high flows and/or high pressures, improve safety, increase speed and add to the efficiency of the cleaning process. The ultra-high pressure intensifiers and pump manufacturers seem to have taken the reserve direction of development by starting with highly sophisticated automation and then developing portable equipment with hand held accessories. Heavy industry tends to have specific applications that must be done on a regular basis and lend themselves to the development of automated high pressure water jetting systems. The following paragraphs discuss automated water jetting systems to do a number of industrial jobs that are improved by the use of the technology. In industrial applications, systems can be permanently installed and may include electric driven high-pressure pump units, powered movement of the cleaning nozzles and the manipulation of the item being cleaned. In the case of a large but portable item to be cleaned, a cabinet or special room can be designed so the work moves through the cleaning chamber. Good examples are found in the automotive industry where auto bodies, paint carriers and conveyors are cleaning in automated booths. The following paragraphs also discuss hydraulically powered, automated systems using pulsed nozzle to remove explosives and rocket propellants. Another example of a hand held process that developed into an automated method of cleaning can be found in the petrochemical industry. In the 1970's chemical plants and their contractors used hand held guns to clean chorine cells, but in the 1980's portable air powered fixturing devices were available to rotate the nozzle while moving it vertically and horizontally. With the installation of an electric powered high-pressure pump, the system could be installed with a remote operator controlled cleaning station. In addition to the nozzle movements, the rotating lance could move into and out of the chlorine cell being cleaning thus allowing an X,Y,Z coverage.

8.1 Chlorine Cell Cleaner

By the 1990's chemical plants were more familiar with the benefits of automating some of their cleaning jobs, so a customer requested a system to clean their large chlorine cells that are used for making the gas from salt brine. The customer had been using a high pressure pump unit and a hand held gun capable of 10,000 psi at 10 gpm to remove the asbestos coating from the cell anodes and now wanted a system that would clean the cells while rotating them for access to all sides. The ideas that were discussed included:

- A cleaning lance that moves in, out and rotates the high pressure nozzle
- An indexer that moves the lance up, down and from left to right
- A work table that supports and rotates the large chlorine cell for cleaning
- A control console to operate all the automated functions of the process
- A 300 horsepower electric driven high pressure pump unit for 10,000 psi operation
- A hydraulic power unit to operate the system movements

Figure 5 shows the device called an indexer to move the nozzle for cleaning the chlorine cell. The complete system designed with the parameters listed above was installed in the customer's facility, which included a containment room for the cleaning process, a control room for the operator and a pump room for the high-pressure pump unit capable of producing 10,000 psi at 42 gpm. The increased horsepower available for cleaning and the automated system improved the cleaning effectiveness. The customer's personnel were exposed to less danger when protected in a control room when operating the equipment. Figure 6 shows the Chlorine Cell rotation device and Figure 7 shows the System Control Console during testing. The 300 horsepower pump unit is shown in Figure 8.

Figure 5 – Indexer Device for Chlorine Cell Cleaner

Figure 6 – Rotating Device for Chorine Cells

Figure 7 – System Control Console

Figure 8 – 300 horsepower pump unit

8.2 Water Expeller Cleaning System

Another customer wanted to automate a process to clean their rubber dewatering equipment. A piece of equipment that was called a "Continuous Expeller" is used to squeeze the water from rubber being made by this plant facility. The main problem is that the rubber extrudes out of the narrow openings in the expeller during the dewatering process so a regular cleaning is required to keep the equipment operating. The job is not pleasant using manually operated water blast equipment and handguns because of the heat and humidity in the expeller equipment room. The customer requested the following features for the automated equipment:

- Be able to run continuously in a dirty, hot and humid atmosphere
- Have a cleaning cycle of about ½ hour for each expeller
- Include an electric driven high pressure pump unit with minimum flow
- Equipment to be removable for servicing each expeller

The first phase of the proposal was a design concept for the cleaning mechanism, a recommended pump size and a budget price for the system to clean four of the expellers. Later tests and prototype hardware proved that 20,000-psi at less than 10 gpm would do the job. After reviewing the concept, it was decided that a PLC (programmable linear controller) would be desirable to control the functions of the system along with the automated valves and air logic. The final design changed when the customer agreed to remove the cabinets over the expellers to allow better access. The mechanism was tested on the job site and was developed into the complete system.

8.3 Runway Cleaner

One of the early runway-cleaning high-pressure pump systems was seen at Aqua-Dyne in 1977 when the company was working with a customer named Bob White. It seems that no one remembers runway cleaning using high-pressure water before Bob White. He started by using a big rig and early pumps with their large horsepower requirements used lots of water in the 5,000-psi range to clean rubber from the runways. This type of equipment is expensive to buy and operate, but also takes extra time to supply the large amount of water used during operation.

Next came 10,000 psi, but still used large quantities of water without giving satisfactory rubber removal and paint strip removal. This type of equipment grew to 400-500 horsepower and up to 15,000 psi at 50 gpm without the desire results. Then, Ultra-High pumps to 60,000 psi were tried using spray nozzles configurations that tended to polish the runway surface and still not produce the proper cleaning. Around 200 horsepower is better with the right nozzle technology proved to be a better way to go. The latest hardware includes one or more rotating spray bars with pressure to 40,000 psi to remove difficult deposits without damaging the runway. The right idea for modern times may be to reduce the horsepower, flows and size of the equipment that is used in a runway cleaning business. The smaller unit can use a spray bar for some of the work such as washdown, by mounting it to the side of the trailer and a rotating head can be used for heavier cleaning such as rubber and paint removal. In the early 1980's Bob once walked into Tritan and made a deal with the owner to build a runway cleaner, if he would send someone to Saudi Arabia for start-up & training. This and other stories about Runway Cleaning are covered in an article called WHERE THE RUBBER MEETS THE ROAD.

8.4 Automotive plant systems

High pressure pump systems have been used to de-burr machined parts such as automatic transmissions or cleaning sand from engine block castings around the automotive industry for a number of years. Automated systems used in manufacturing include robotic cleaning heads using 20,000 psi water jets to remove the paint buildup on vehicle paint carriers and simple nozzle arches to wash auto bodies on a production line. The paint booth grate cleaning pump systems evolved from hand-operated water blasting guns into power rotating nozzles in lawnmower type equipment. The high-pressure pumps, controls and piping systems are permanently installed using sound attenuated enclosures that have become part of the automotive plant design.

8.5 Rubber Crumb Conveyors

Some rubber plants produce a product called rubber crumb that is later made into finished products. High-pressure water jets proved to be a good way to clean the Rubber Crumb Dryer Belts built by Proctor & Schwartz and others that are used in the manufacturing process. Several companies such as Goodyear and DSM Copolymer used contractors with hand lances or mechanized nozzle movement systems to do the cleaning. When it became feasible to install permanent equipment, fixed automated systems were designed and installed. One design uses a trolley track with a high-pressure swivel to move across the surfaces to be cleaned. The devices can be air powered or just the swivel with its cleaning nozzles may have air-powered rotation. To get the continuous movement of the swivel carrier, a scotch yoke attached to a chain loop can be used to provide the back & forth motion for conveyor coverage.

8.6 Cleaning Cabinets

Cleaning Cabinets have been used to contain the debris that is being removed by a device such as a high-pressure water jet. Investment castings that are produced with tree type pouring channels or intricate castings with a pour spew and passages are good candidates for cleaning cabinets. This type of cabinet was developed by water blaster manufacturers in the 1970's and proved to be an economical and safe way to rapidly remove the casting material from the metal parts.

8.7 Cable Cleaning Station

A Tow Cable Wash Station was developed for the Westinghouse Electric Oceanic Division in 1988 to clean and rinse the cable used for "towed array" equipment. After the cable was used in salt water, it collects salt, marine growth and debris so it has to be cleaned. The wash station was designed to allow the cable to be pulled through for cleaning at a rate of 13 feet per minute. The cart mounted unit consisted of a Hypro series 8600 twin plunger pump, 1-1/2 HP electric motor and wash chamber with self-pulsed nozzles to produce 1000 psi at 3 gpm.

8.8 Airplane Cleaner

A Prototype Pulsed Jet Cleaner was part of a research project for the US Air force to clean airplanes. Self-resonating nozzles were used with a Cat 650 plunger pump and a 10 HP motor to produce 2500 psi at 6 gpm. The portable unit was tested in 1985 on cargo plants at Robins Air force Base near Macon, Georgia. For greater coverage, three nozzle lances were fitted to one shut-off style handgun. Detergent could be applied by a lower lance supplied by a separate lance at a pressure of 100 psi and flow of 2.2 gpm. The type of nozzles used in this prototype was also used to clean automotive vehicles, removing ice from the topsides of ships and cleaning various surfaces. A January 1991 article in Cleaner Times described a hot water washer using the pulsed jet to clean oil and dirt from the flight deck of the USS John F. Kennedy. The unit produced 3,000-psi at 5.5 gpm of water that was heated by a jet fuel fired burner and had a wet/dry vacuum. The features allowed good cleaning of the carrier deck and tie-down holder cups.

9.0 SPECIALTY PUMP SYSTEMS

High Pressure pumps are used for special purpose systems such as removing the propellant from rocket motors. Similar equipment is also used to remove coatings or unwanted material in drill pipe, casing and tubular shapes such as industrial pipe. Rigid lances and flexible lances using high-pressure water jet nozzles first cleaned oil field tubulars and heat exchanger tubes. Later, tube cleaning machines were developed with a rotating lance on a track to improve the safety and efficiency of cleaning the internal diameter of pipe and tubes. The technology for cleaning defective rocket propellant from rocket motors may have developed independently, but was definitely influenced later by the tube lancing machine designs.

9.1 Rocket Washout System

A water jetting system using a pulsing nozzle to remove propellant from rocket motors was designed and built for a group outside the USA. The special nozzle technology allowed the use of 10,000 psi instead of higher water jet pressures. The rocket motors ranged from .5 meters in diameter by 4 meters long to 1 meter in diameter by 6 meters long. The goal was to build a system that could operate at lower pressures that are well below the level capable of detonating explosives or propellants, provide for a man-in-the-loop to observe and control, integrate automation and simplicity while maintaining safety and provide a more efficient process free of foam. Earlier hot water washout systems created foam when attempting to remove rocket propellant.

9.2 Nozzle Design

Previous work done with cavitating and pulsing nozzles to remove high explosives from munitions and solid propellants from missiles and rocket motors contributed to the design of a complete system to suit the customer's unique requirements. The hardware was developed to fit into a facility in Pakistan and had features that allowed the use of a standard high pressure pump to operate at lower pressures, prevent detonation of the propellant and to integrate automation while providing operator safe control of the operation. The complete system consisted of a tubular washout cradle, lance mechanism, high pressure pump unit, control console, effluent catch tank, water filter, make-up water tank, water chiller, filter transfer pump and filter tank pump as shown in Figure 9. Figure 10 shows the Rocket Propellant Washout Lance and Figure 11 shows the nozzle assembly in the testing set-up.

Figure 9 – Rocket Washout System

Figure 10 – Washout Lance

Figure 11 – Specialty Nozzle for Washout

10.0 VESSEL CLEANING SYSTEM

Uraca reported that a customer in the USA was looking for an economical and environmentally safe means of cleaning an existing vessel used in the production of specialty plastics. The project required that the cleaning system meet or exceed the following minimum specifications

- Clean the vessel in less than one hour
- System to be fully automated utilizing the plant DCS system
- Require no manual entry into the vessel
- Must be leak free to avoid the release of toxic gases from the vessel
- The system would need to demonstrate a short return on investment
- The system had to be delivered in less than six months

Previously, cleaning was done on a random basis with manual equipment. The customer used high-pressure equipment that required occasional manual entry into the vessel. This process was not only slow, but was also hazardous to the workers cleaning the vessel. Exposure to the toxic gases and the use of high-pressure water was a constant potential danger to those workers that had to enter the vessel for cleaning. Talks were initially held with numerous potential suppliers. The technical objective was to use existing manways (existing entry openings) and to maintain as much of the existing reactor pipe work as possible without having to make room for the cleaning system.

11.0 JETTING WITH HOT WATER

Hot water pressure washers are a common part of the small pump market. Pressures usually run in the 1,000-psi to 3,000 psi and may incorporate an on-board heater fired by fuel oil. When it comes to offshore hot water pressure washers, electric heaters are often used to elevate the temperature of the water supply to the positive displacement pump.

These electric, hot water, pressure washers are often rental units that are compact and portable, but the new offshore complexes are being designed with cleaning systems permanently installed. The Kizomba A, Kizomba B and Kizomba C facilities have a high pressure, hot water washdown pump unit to serve multiple wash stations on these offshore platforms. A high-pressure Hot Water Washdown unit for a Major Oil Company's offshore platform was manufactured to specification written by a well-known engineering group. The changing rules of the game will be discussed as they apply to this water-jetting package built in Houston, Texas. The documents, drawings, electronic submittals, approval cycle, inspection and final acceptance testing required for the project, doubled the scope of work for the equipment. The new way of doing business with major oil companies includes an increase in the scope of engineering and a large amount of documentation to complete each job. There will be a discussion of the 95 submittals that were required and how it affects the cost and schedule for building a pump system. The increased amount of work extended to the next phase of this project for the same oil company and it is appearing in specifications from other oil companies too. There are some unusual aspects of this project such as computer controlled jetting pressure and water heating and there will be photos in the paper and slides for the paper presentation. With oil companies demanding similar specification for their equipment, the trend cannot be ignored if a pump supplier is to participate in major oil company work. The second unit built for offshore is described in a paper by Weimin Dai who was the project engineer.

12.0 CONCLUSIONS

Companies around the world have contributed to the evolvement of the high-pressure pumps, intensifiers and automated systems to harness their useful power. High-pressure pumps and systems are used almost every industry in modern times. The technology has been found effective in reducing cost and improving results over other methods of accomplishing a given task. Those in the field of high pressure and ultra-high pressure should be encouraged to continue the good work with integrity.

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