Hydraulic Ram Pump
Research Programme

D T U

NEW DEVELOPMENTS IN HYDRAULIC RAM PUMPING

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This technical release has been written more for ram pump enthusiasts, researchers and manufacturers than for installers and users. It describes the main current trends in system and pump design.

1 GENERAL TRENDS

The ram pump is a 'mature' technology. Over the last two centuries pump designs have stabilised and many variations to the basic configuration (of drive pipe, pump, pump house and delivery pipe) have been tried. One might think that no further significant change was likely in the ram pump itself or in the system in which it is used. However there are changes occurring in both pumping needs and in materials.

Before the invention of petrol engines or the arrival of electricity on farms, the ram pump was in many locations the only feasible way of lifting water from streams or springs to neighbouring hillsides. In consequence a high cost was tolerated; strong but expensive pumps made from cast steel, gunmetal and brass were used. Today there are more alternatives, so that ram pumping can only hold its 'market share' in water supply for humans and for cattle by becoming cheaper and simpler.

All over the world water is getting scarcer and dirtier. In consequence ideal sites for rarn pumping - where a large flow of clean water drops steeply - are becoming fewer. Quite often the water requires cleaning if it is to be used for domestic purposes. There are various possible responses to this problem of polluted drive flow. One is to filter the delivery flow. A second is to use an indirect ram pump that permits falling dirty water to power the raising of clean water from a nearby source. A third is to concentrate on applications like cattle watering and irrigation where water quality is less important.

Filtering and disinfection are well understood, and the technical options for applying them are increasing in number. The availability of only one or two watts of electricity, say from a small photo-voltaic panel, now enables chemical or ultra-violet sterilisation to be performed at a household or village scale. Adding such processes to a ram pumping system may require other design adjustments, for example those to permit delivery flow only in day light hours.

Indirect pumping is a technique known for a hundred years or more. Indirect pumps are still manufactured but they are complex and hence costly. They have more wearing parts than normal ram pumps and they require a source of clean water close to the dirtier flow that drives them. One might argue that to require such elaboration in system installation and maintenance is to head in the wrong direction. Field experience suggests that the use of ram pump technology is already severely limited by people thinking it is 'too complicated'.

It is the authors' experience, mostly in an African context, that even after a 3 weeks' training course many water technicians do not have the confidence to survey, design and install a ram pump system. The design rules seem complex and they fear making any mistake that might cause a system to fail. Yet systems do occasionally fail - through wear and corrosion, insufficient drive flow or flood damage, siltation or blockage, theft or malicious damage. It is not possible to build a perfect system.

With petrol-engine pumping at its simplest, the user carries the pump to site, drops a suction hose into the water source, rolls out the delivery hose and starts the pump. With electric powered pumping using mains, photo-voltaics or transported batteries, the procedure is a little more complex. Ram pumping is more complex again. There has therefore been a growing interest in simplifying the technology, especially in order to serve irrigation operated by peasant farmers.

2 SIMPLER PUMPS

A pump normally comprises an adjustable impulse valve, a (non-return) delivery valve, a pressure vessel to smooth out the pulsating delivery flow and an anchorage or cradle. Where 'free' air is the buffering medium in the pressure vessel (which must be vertical to work properly), a third ('snifter') valve is needed to replenish this air.

Simplifications can take a number of forms, but the main ones of current interest are

- removing the mechanism to adjust the drive flow,
- replacing 'free' air by 'contained' air,
- simplifying the anchorage of the pump and its attachment to drive pipe and delivery.

Removing the tuning mechanism of course removes all the benefits of tuning, namely the ability to adjust the pump to match the drive flow locally available. Under some circumstances, especially when only a small fraction of stream flow is needed, there is no great merit in being able to tune. Where a manufacturer produces a range of pumps it is normal for each step up in size to correspond to a two or three fold increase in maximum drive flow. An untuned pump is effectively permanently set to its maximum (or 'rated') drive flow. Thus using such pumps singly will restrict the drive flow, and hence delivery, to one of a few widely spaced values. If however several (say three) identical pumps, or two pumps of different size, are used in parallel, it is usually possible to get within 25% of any ideal drive flow. In fact there are four distinct alternatives to on-site tuning for matching pumps to available flow, two of them applicable when the system is installed and two when it is in use.

During *installation* the drive flow capacity of a system can be roughly selected by choosing the right number and size of pumps to be run in parallel. Alternatively pump(s) can be used that are 'preset' to a particular drive flow. This lower level of adjustability not only simplifies pump design (e.g. it can be provided by having two or three different weights of impulse valve), but removes the possibility that the user completely mistunes his pump. Such mistuning through operator ignorance is quite common in high technology systems as well as in the simple ram pump ones we are discussing here.

During *operation*, there may be a need to respond to a fall in available stream flow. If pumps are not tunable this can only be done by reducing the number of pumps in operation or by running them all intermittently. Using the 'three same size pumps' or 'two different size pumps' arrangement recommended above, it is possible to follow any changes in stream flow by changing the number of pumps in use. Intermittent operation by contrast can be used with only a single pump but requires much more operator activity and also a reservoir capable of storing at least 2 hours drive flow. In practice intermittent operation, where the user turns on the pump when the reservoir is full and off when it is empty, is very rare. It could become more common where small-farm irrigation is the pumping application. Technically it should also be possible to use a self-priming siphon to achieve intermittent operation without human intervention: the authors know of no example of this being done.

Given the desirability of having more than one pump running in parallel for reliability reasons, the relative rarity of requiring very close matching of system drive flow to stream flow (often extremely variable) and the likelihood of mistuning by inexperienced operators - we may expect to see more simple pumps that are untunable or are tuned ('preset') only during manufacture.

Using "contained " air to buffer the pulsations in delivery flow has real advantages over using a conventional air vessel. By "contained" air or "air packet" we mean air in a bladder or closed-cell foam. Normal commercial pressure-surge limiters in water pipelines use diaphragms to separate the air from the water, however such diaphragms are difficult to make and to seal and are therefore expensive. By contrast closed-cell foam such as bubble-wrap has already been used in a number of small ram pumps. The advantages of substituting air packets for the free air of a conventional pressure vessel are several. The containing chamber need no longer be vertical, air cannot be lost through tiny holes in welds or fittings, the snifter valve is no longer necessary, the pump can be operated under water. Disadvantages are the possible fatigue failure of the air-containment materials, slow loss of air through the walls of bladders or foam and the significant reduction in air volume at start up.

Consider a conventional air vessel of volume 10 litres in a pump delivering to 90 meters. Initially, before start-up, the air is at atmospheric pressure (1 bar). At start-up the absolute pressure rises rapidly to 10 bar (9 bar 'gauge') as the air is warmed and compressed. It then cools until its volume is about 1 1itre, namely one tenth of its initial value: the air vessel is now nearly full of water. Over a period of hours however the air is replenished via the snifter valve to its original volume of 10 litres. The pump may run rather noisily until this has taken place.

If however a closed air packet replaces the conventional free air, there is no replenishment mechanism, so throughout the run time it remains at 1 litre. It therefore is necessary to provide an air packet whose initial volume is equal to:

V_{init} = air volume required in operation (V_{op}) $\times$ delivery pressure in bars absolute.

(Note that 10 meters delivery head corresponds to 2 bars absolute, 20 meters to 3 bars etc.)

Recent research and experimentation suggest that the air volume in operation (V_{op}) can safely be as little as twice the volume of water delivered per cycle. [The pump efficiency does not fall significantly compared with when V_{op} is large, and the overpressure of about 30% is usually also tolerable from a fatigue point of view.] An irrigation pump may only lift to 20 meters, so initial air volume V_{init}, is only 3 times V_{op}, whereas a domestic supply pump may lift to 80 meters (V_{init} = 9 times V_{op}) or higher. We would therefore expect this air compression problem to be more severe with high-lift pumps. However as the delivery head is increased (while the drive head and drive flow are kept constant) the volume delivered per cycle goes down. The combination of these effects means that for a given size of pump, the appropriate initial air packet size does not vary much with delivery head. In practical terms, the minimum initial packet size relates to pump size roughly as shown in Table 1:

This table indicates an initial air packet volume, and therefore vessel size, equivalent to 1 m of drive pipe (or less length of a larger diameter) should be sufficient: this is a tolerable size.

With an air packet, pump design can be simplified to essentially an impulse valve followed by a packet-enclosing horizontal tube entered via the non-return delivery valve. This results in a fairly compact design of pump that can be placed under water to maximise drive head and to reduce noise. Although there are some particular problems that can arise when operating under water – for example sucking debris in through the impulse valve, increased vulnerability of flood damages and difficulty of access for tuning – in many situations the advantages outweigh the disadvantages.

As materials further improve we may expect more ram pumps to incorporate air packets or even a diaphragm instead of traditional air vessels.

Simplifying the pump attachment is a particular requirement for irrigation use where ram pumps and even drive pipes may be removed at night and will certainly need to be removed at the end of the dry season. The shock forces on pumps when they are in use are large, so any anchorage has to be sturdy. Already it is usual to bolt pumps onto a permanent (i.e. concreted-in) cradle. There is now interest in providing clip-on arrangements both between pump and cradle and between pump and drive pipe, rather than using nuts, bolts or wedges.

3 NEW MATERIALS, LOWER COSTS AND HIGHER PERFORMANCE

Materials For long-life pumps, traditional construction materials are largely suitable. By contrast, new materials have particularly found their place in cheap ram pumps of modest but adequate performance. During the last twenty years metal piping has largely been superseded by plastic, especially PVC, ABS and HDPE. It is therefore

Table 1

Drive pipe size (ID)	mm	25	50	75	100
Assumed driveflow	litres/min	25	100	250	500
Packet size (for *drive* head of 2 meters)	litres	0.15	0.60	1.50	3
of 6 meters)	litres	0.45	1.80	4.50	9
Volume of I meter of drive pipe for comparison	*litres*	*0.5*	*2.0*	*4.4*	*8*

tempting to use these rust-proof and easily worked materials for constructing ram pump bodies. Unfortunately the poor stiffness, fatigue strength and sunlight resistance of plastics poses problems.

The water-hammer effect that underlies ram pump operation is dissipated in very elastic, or worse energy absorbing, materials. For this reason we try to avoid accumulation of air in drive pipes and we look for a high level of wall stiffness in them. The maximum height a ram pump can deliver to is approximately $h_{max}=\nu\ C_{dp}/g$. Where ν is the maximum water velocity in the drive pipe and C_{dp} is the velocity of sound in that water. It can be shown that for an infinitely stiff pipe, C_{dp}/g is about 140 meters height per meter/second, in a steel pipe it is typically 120 but in a plastic pipe it is only about 30.

[The formula normally used is:

$$C_{dp} = C\sqrt{\frac{1}{1+\frac{DG}{tE}}}$$

Where C is the velocity of sound in water, D and t the diameter and thickness of the plastic pipe, G the stiffness of water and E the stiffness of the plastic.]

This effect shows itself in a plastic system being only able to deliver to about 30% the height of an all-steel system. For really high head deliveries steel drive pipe is essential. For delivery height under 50 meters, plastic drive pipe is adequate

All materials show 'fatigue' in that a loading that they can tolerate easily if it is applied only a few times may cause failure if applied millions of times. In a ram pumping system, the pump and drive pipe experience between 15 million and 100 million pressure pulses per year, so fatigue failure is a real danger. For plastic drive pipes it is usually sufficient to select a pipe pressure rating of 3 times the delivery pressure. For plastic pumps, fatigue failure is so likely that either they are metal reinforced or they are restricted to use with very low delivery heads. Apparently no one is making pumps out of glass reinforced plastics (GRP) despite this material having suitable stiffness and fatigue performance.

Injection moulded plastics are used in centrifugal pumps and hand pumps. They could be used for ram pumps too, but the small production runs do not at present justify the high tooling costs. A few experimental pump bodies have even been made of concrete whose inertia may act as a substitute for strength in the face of sudden forces. The material is cheap, though heavy, but the problems of getting really high densities and of sealing the joints between concrete sections have apparently defeated concrete pump designers.

Certainly the use of simple plastics in small or low-lift ram pumps is now well established alongside that of metals for higher lifts. It seems unlikely that more complex materials or processes will be soon employed to make these devices.

Lower costs come from use of fewer, cheaper or 'easier' materials, from mass production and from design simplifications. Understanding of ram pumps is better than in the past and this had led to a few design changes leading to lower costs.

Mass production of complete pumps is constrained by small markets, while attempts to assemble the pumps from mass-produced fittings have not generally led to either high performance or to much lower costs. Fittings are not cheap if used in any number: pumps made from them are generally clumsy and have too many parts.

For fabricated steel pumps the now ready availability of square section tubing offers simplification of design and assembly compared with traditional round tubing. Square tubing is not efficient at containing high pressures but this is not normally a problem at all but the highest delivery heads. Fabrication is better suited to some pump-using countries than employing iron casting, machining, forging or threaded connectors. Welded joints can be opened again if necessary by cutting them out with an angle grinder

Probably the greatest need for cost cutting is in irrigation applications. If a siphon drive pipe could be developed (requiring the pump to be submerged), the installation costs of irrigation pumps could be reduced substantially. Some effort is being applied to designing essentially portable systems for use with dams as low as 500 millimeters, where the pump and its drive pipe can be quickly disconnected from anchorage and dam respectively.

High performance takes various forms, such as higher efficiency, higher delivery head, quieter operation and greater durability. It seems that little theory was used in the past when designing either pumps, or complete systems. Today ram pumps have something of a fascination for analysts so that there are several publications that aid high-performance design. For example the main sources of inefficiency are well documented and it is not hard to devise an economical system with an overall efficiency as high as 70%.

In Nepal, the Andes, Rwanda and elsewhere there is some need for pumps that lift as high as 200 meters, well beyond the limit of normal machines. The procedures and materials for achieving very high heads are known, but so far the market for such pumps has been too small to cover the costs of fully developing them. DCS, Butwal in the Himalayas have reached 180 meters lift with some reliability.

Quiet operation has been traditionally achieved by placing pumps and drive pipes underground. For years some pumps (for example the Blake's machines) have used rubber impulse valves in otherwise metal systems to reduce noise. The move towards plastic drive pipes may lower efficiency a little, but it beneficially converts high-frequency 'clanging' into less intrusive low-frequency 'thumping'.

Only in the area of durability can one find no significant improvement. Perhaps the lifespan of cheap pumps has increased a little from its former low level, but it is still far below that achievable with traditional 'over-designed' machines.