Harvesting the energy of mine water

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Abstract

New and creative approaches to cost-effective water management practices are possible with the further development of shaft- or piston-driven energy conversion technologies that can be adapted to and powered by a new lever-based water motor. A pilot-scale version of the patented water motor technology, simply known as the M T Water Motor, has been constructed, documented, and demonstrated proof of concept. An interactive spreadsheet model of a horizontal water displacement pump coupled to and powered by the water motor includes 19 input variables and calculates output results for 17 additional design considerations. The Excel spreadsheet model allowed us to evaluate and optimize the site-specific design capabilities of the low-head, lever-based technology. The ability to raise water using the potential energy of water can increase the land availability necessary to expand existing passive and active treatment capabilities and to create new treatment approaches. Furthermore, the M T Water Motor is capable of being coupled with established mine water aeration and treatment technologies, including the ILS.

Keywords: Water motor, raising water, mine water treatment, low head hydropower, potential energy

Introduction

Researchers have been attempting for decades to increase the efficiency and cost effectiveness of turbines designed to operate using low flows and low-head water sources (Kuecken 1979). When generating hydropower, the head is the distance that a water source must fall before meaningful power is created. A new hydropower technology, the M T Water Motor (MTWM), which harvests the *potential energy*, rather than the *kinetic energy* of the water, could address this need.

The MTWM (Fig. 1) is a simple, innovative hydropower alternative that can aid existing and help create future water management practices. This unique technology can be used to inexpensively generate meaningful amounts and varieties of renewable energy products from a broad array of low-head natural and man-made water sources and locations including natural streams, surface and storm water runoff, industrial/power plant/treatment plant discharges, locks and dams, and above-drainage mine pools, as well as other sources that exhibit adequate head but are not commonly imagined as hydropower sources. The management of water weight (or potential energy) using a lever-based system lowers the cost and maintenance requirements, and improves energy harvest flexibility and efficiency, and the magnitude of energy output for low-head settings (≈ 6.1 m (20 ft) when compared to conventional hydropower technologies. The MTWM's varied flow capability makes it possible to efficiently extract energy from an enormous number of currently untapped low-head water resources.

The MTWM is a lever-based water-powered motor capable of harvesting any flow rate (water weight) with one or more units coupled to a piston- or shaft-type energy conversion technology (Ackman 2012, 2021). The water motor can be described as a simple machine, consisting of four orchestrated lever systems. Two prototypes of the device have been successfully constructed and evaluated. An interactive Excel model has also been developed for the design and performance prediction of a horizontal displacement water pump coupled to the water motor. The new interactive water pump model allows site-specific variables and hardware to be evaluated including operating flow rate, pipe size, and raised head flow rate (figs. 2, 3). Comparing the approach to the conventional hydropower turbine, the new water motor serves a similar function as a water turbine since both components can turn a shaft, albeit using different energy types.

Enhanced Mine Water Treatment Using the M T Water Motor

The MTWM could enable innovative and economical approaches to the surface treatment of mine drainage and enhance underground mine pool management practices. Surface treatment of mine water includes passive, semi-passive and active treatment of mine-influenced waters. Underground management practices include treatment and discharge of clean water with the waste remaining underground and water quality management of the developing local or regional mine pool. The following briefly discusses these conceptual approaches using the pumping capabilities of the MTWM.

Passive Treatment

Passive treatment systems require longer retention times and greater land space than convention mine water treatment (Zipper et al. 2014). The primary advantage of a passive system, like the MTWM, is that it does not need constant maintenance or upkeep to operate. The ability to raise water 50 ft (18 m) could create meaningful space for expanding these effective and land-intensive passive treatment systems that are currently limited by the amount of available land. Alternatively, or in conjunction the MTWM-generated power could be used to aerate mine water through the exchange of a water pump with an air pump attachment. Presently, supplemental aeration coupled with passive treatment offers the opportunity for more efficient oxidation of mine waters in confined settings, which in turn would reduce the land requirements. There are a several ways to employ the MTWM with a water pump attachment to supplement or replace existing aeration practices. Two fundamental approaches would include recycling a portion of an aeration pond discharge to extend atmospheric contact for increased oxygen transfer or simply by creating a water fountain within the pond. Another approach to mine water aeration involves the coupling of the MTWM and water pump to the in-line system (ILS), as discussed below.

The In-Line System

The MTWM can be used in tandem with another water-powered technology, to improve mine water outcomes. The ILS has been proven to be an effective mine water approach for both coal and hard rock mine drainage. The ILS, which operates without moving parts, can be configured as a passive aeration system or a simultaneous aeration and active chemical treatment system (using CaCO3, CaOH2, NaOH2). Water pressure (20 psi, 137.9 kPa) operates the ILS with 50 ft of head and piping, or alternatively by a water pump (water or power driven), using a venturi to add the air and, if needed, alkalinity. Furthermore, the ILS can effectively treat a broad range of mine water qualities (Ackman and Kleinmann 1984, 1991), and can effectively oxidize nearly 900 mg/L of Fe^{2+} in only 30 seconds of contact time in the system (Ackman and Edenborn 1997; Ackman and Kim 1996). In addition, once the iron is oxidized, the ILS can rapidly remove manganese at circumneutral pH, while conventional treatment approaches typically use an alkaline pH as high as 10 for manganese removal and subsequently must lower the pH of the water before discharging it.

The MTWM and ILS can be used as either a closed-loop or open-loop operation. A closed loop system would simply use the MTWM to raise the mine water in a pipeline to the targeted elevation to create water pressure and then return flow to the ILS without leaving pipeline, providing aeration or aeration and neutralization capability. The open-loop operation involves pumping mine water with the MTWM into raised temporary storage and discharged from pipeline for subsequent gravity-driven batch treatment with the ILS.

Another related conceptual approach is to capture the plant's treated discharge as a water source (assuming adequate head) for powering the MTWM to operate the ILS for aeration purposes or to simply pump water in a beneficial manner. The strategic injections of oxygen-saturated flow within an existing treatment operation could support plant effectiveness and efficiency relative to iron oxidation, oxygen levels of the discharge, and meeting effluent standards. This form of support during times of high flow or varying mine water quality becomes a polishing step and has the potential to reduce expansion needs, if relevant.

Limestone Diversion Wells

Limestone diversion wells (LDWs) also operate with water pressure that can be created with 50 ft (15.2 m) of head. Water pressure is necessary to raise and agitate a limestone bed located in a down-gradient tank. The resultant autogenous grinding of the limestone creates an alkaline slurry) for water treatment purposes. The water pressure can be generated in the same manner as the closed-loop ILS described above. This pressurized water would be applied directly into the bottom of the LDW suspending the limestone and autogenously grinding the limestone. Due to the need to replenish the limestone, LDWs are classified as semi-passive treatment systems (Doc Fritchey TU 2000).

The ILS, LDW, and passive treatment methods can operate with either continuous (raised storage) or intermittent flow water created by water pump cycle time. The simplicity of the water motor and its ability to raise water allows for future beneficial uses of mine water, such as community-scale recreational lakes/ponds, irrigation waters, fish hatcheries, and creating geothermal capability for heating and cooling for community use (Watzlaf and Ackman 2006).

Underground Water Treatment

The use of conventional methods to treat mine water underground is not novel, and the ILS has also been proven effective in an underground environment. Yet both methods require power for pumping the water. It is important to realize that an underground pumping network in an active mine is quite extensive and requires delivering electricity long distances throughout the active and mined-out workings to power pumps that manage the influx of groundwater. The MTWM is considered capable of underground treatment within the coal seam. A critical consideration is the dip of the coal seam. For example, a coal seam with a 5% dip implies a 1.5 m (5 ft) drop every 30 m (100 ft); therefore 6 m (20 ft) head can be obtained with a 122 m (400 ft) long entry, and of course, the regional dip of a coal seam can be variable over a short distance.

The water quality of a developing mine pool in an active mine can be adversely affected by seepage from a flooded up-dip abandoned mine. It is conceivable that the energy of the collected seepage could be used to strategically reinject a portion of the collected flow (treated with alkaline material) back into the adjacent abandoned mine pool through roof holes. This would be a form of in-situ treatment with the intent of improving the water quality in the abandoned mine seeping through the coal barrier. In-situ deposition of sludge within the abandoned mine voids in turn would hopefully seal off a portion of the leakage while reducing operating, pumping, and treatment costs. Directional drilling and remote operated vehicles and adjacent mine maps would be required.

The coupling of directional drilling capabilities with the MTWM would permit access to above-drainage flooded mine voids from the surface near the same elevation. This approach provides an opportunity to identify ideal surface treatment location(s) with adequate head and land space and to reharvest the energy of the mine water.

Why the MTWM Works

The output energy of existing small-scale or low-head hydropower technologies (e.g. microturbines) is limited because extracting the kinetic energy of water becomes inefficient at this scale. Conventional hydropower production is also limited by poor water quality and high-water temperatures. The MTWM is considered capable of harnessing and expanding the efficiency, capabilities, and output of low-head hydropower globally through its ability to harvest ***potential energy***, rather than kinetic energy.

This simple machine can turn a shaft or push a piston. These two capabilities are powered by the weight of temporarily raised and captured water (e.g. vessels containing 189–1890 L [≈ 50–500 gal] of water) that is cyclically discharged at the lowered position after the energy has been harvested by a shaft or piston operation. The magnitude of torque created by the MTWM and its availability for pumping water is a function of on-lever storage weight, lever length (and strength), fulcrum height, and resistance (e.g. a check valve) to maintain the raised position of the receiving tank until full.

The see-saw like motion and the catch and release operations of the water motor create a cyclic energy harvest and discharge at a rate determined by flow and captured volume. However, the use of two or more water motors in parallel would allow continuous rather than cyclic pump flow. An analogy is the operation of a two-piston engine.

Although the head requirements of the MTWM differ substantially from those of conventional hydropower, they share the same trait of increased energy output with increased flow rate. The operating head requirements of the water motor are dictated by its structural dimensions, components, and orchestrated lever movements in space. The elevation of the centered inlet water point (top 4-way pipe fitting; Fig. 1 top) of the upper directional flow lever defines the operational head. A relevant factor relating to this defined head is the positioning and the physical dimensions of the raised lever and tank to receive the discharge of the lowered directional flow lever (located above the working lever). The height of the raised vessel water inlet must align with the discharge from a lowered directional water lever for receiving feed water flow (see Fig 1. bottom). It is for this reason that the term low head implies ≈ 6.1 m (20 feet) or less for industrial settings.

Geometry is a friend to this simple machine with respect to the ability to custom mold and shape the volume and height of containment vessels (using 3-D printing) and the required operational head. For example, equivalent volumes of water can be stored in taller or shorter vessels with a larger diameter representing a pancake-like effect to maintain volume and weight. Alternatively, storage vessels can be placed on the working lever in a saddle-bag-like vessel to reduce head requirements.

However, if additional head is available, discharged water from the upper water motor can be reharvested every additional 6.1 m (20 ft) of decreasing elevation. Thus, an expanded energy harvest can be created by placing additional motors in series in a down-hill arrangement.

Computer-Generated Data

As previously mentioned, an Excel model (Fig. 3) was custom designed for predicting the water pumping capabilities (raised flow rates) using the MTWM. The interactive format of the spreadsheet model allows for the manipulation of many variables and the evaluation of their effects on energy output or elevated water. A further evaluation of the spreadsheet related to elevational pumping capabilities and efficiencies and pumping times and land requirements associated with varied feed water rates (or captured water weight) and are presented in Tables 1, 2 and 3.

Elevation and Efficiency

Efficiency of pumping water remained consistent relative to elevation. Increasing the feed water will increase the raised flow rate yet the water motor will perform at the same corresponding efficiencies (Table 1). An example of raising water 15.2 m (50 ft) using varying amounts of feed water, as shown in Table 2, demonstrates an average efficiency of 32% regardless of feed water rate.

Table 1 *Elevational efficiency of the M T Water Motor*

m	ft	efficiency, %
9.1	30	52
15.2	50	32
30.4	100	17

Table 2 *Average flow rates for feed water and the resulting raised delivery to 15.2 m (50 ft) with a 32 % efficiency*

Feed Water		Raised Water	
L/min	gpm	L/min	gpm
378.5	100	123.8	32.7
757.1	200	247.2	65.3
1,135.6	300	370.6	97.9
1,514.2	400	494.4	130.6
1,892.7	500	593.2	156.7

Water Storage and Time

It is important to realize that the creation and management of a raised water body can take many shapes and forms (natural or man-made, surface, or subsurface) with varying water storage capacities that can serve multiple purposes. The differences in cost, size, and construction of raised impoundment structure(s) can be substantial relative to the temporary or long-term storage requirements and selected beneficial use(s) of the raised storage.

The raised storage volume capacity is important relative to the raised flow rate. Fundamental questions like how long it will take to fill the available storage capacity with water before it is either discharged at a higher elevation or becomes subject to reharvest. When reharvesting raised storage, it is important to realize that the raised water volume represents a percentage of the total volume of feed water (e.g. 32%). Reharvesting raised water with the same magnitude of energy output is possible, albeit on an intermittent rather than continuous basis.

Another fundamental question of raising water includes how much space is needed to accommodate the raised volume. One approach is to evaluate the raised flow rates in terms of required storage space on an area and volume basis. Multiple raised flow rates and the necessary amount time, in days, it would take to raise enough water to fill 1 and 7 ac-ft are shown in Table 3. One ac-ft is equivalent to 1,200,000 L (326,000 gal).

Table 3 *Pumping time and land space needed to store water*

Raised flow rates		Days to fill	
L/min	gpm	1 ac-ft	7 ac-ft
189.3	50	4.5	32
378.5	100	2.3	16
567.8	150	1.5	11

Costs

The primary construction considerations of an MTWM include weight management, the length and structural integrity of the working lever, operational head (feedwater tank and fulcrum), and type of operation (shaft or piston). The water weight that is being projected to be processed through this unique motor is measured in tonnage collected in tanks located on working lever (note Fig. 1 shows 30-gal [113.6 L] testing tanks without resistance). Water or weight containment tanks on a single working lever can be attached to the ends with a platform. Alternatively, larger tanks (e.g.: 1893 L [500 gal] or more) may require multiple axle bearings and working levers that are connected on both ends, creating a platform to manage the larger diameter tanks. Based on the frame and working weight, measured in tonnage (metric or short), a solid concrete base (footer and/or pad) for the motor legs is required to maintain equal balance in the working lever.

The existing prototype of the water motor can be optimized with improved sizing of the working lever. Fig. 1 shows the frame of the water motor constructed of 8 × 6 × 3/16 in. (20.3 × 15.2 × 0.476 cm) tubular steel. Yet varied distinct types and shapes of steel levers (beams) can be used. Potential twisting issues with various lever types can and must be avoided, and potential safety concerns must be identified. M T Water Management, Inc., which has in-house mine equipment repair and fabrication expertise from decades of serving the underground mining industry in the tri-state area, constructed the water motor shown in Fig. 1.

Summary

This new lever-based water motor technology can potentially serve as the basis for innovative low maintenance and cost-saving approaches to the long-term management of mine waters. The ability to harvest potential energy using piston or shaft attachments is unique to the MTWM. This paper introduces an Excel spreadsheet model of a horizontal water pump as the first water motor attachment, which in turn can be attached to other treatment devices such as the ILS and diversion wells. The discussion of the spreadsheet model suggests that meaningful volumes of water can be raised using water weight to various elevations with the potential to reharvest return flow multiple times. We are looking for industrial partners to field test and further develop this technology.

Figure 1 14 ft M T Water Motor without attachment operating

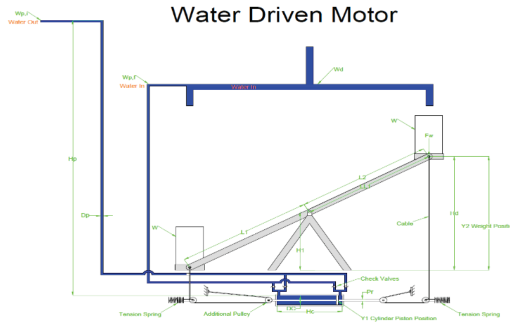

Figure 2 Schematic of Excel worksheet model

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Water Motor with multi directional pumping horizontal cylinder

Inputs

Lever Arm - L_1	Lever Arm - L_2	Attachmen t Point of Cable from Fulcrum LL_1	# of additiona l pulleys for block and tackle	Additiona l Room for Pulleys	Gallons of Water Required in Tank to Complet e Pumping Cycle	Water Flow - W_d	Require d Water Flow - $W_{p,F}$	Piston Diamete r -D_c	Piston Rod Diamete r - P_r	Height of Water to be lifted - h_p	Diamete r of Pipe - D_p	Startin g Angle of Lever	Final Angle of Lever	Magneti c Holding Force to Start Motion	Check Valve	Tim e Step - t	Friction Factor	# of 90° Elbow s in Outlet Piping
(ft)	(ft)	(ft)		(ft)	(gal)	(GPM)	(GPM)	(in)	(in)	(ft)	(in)	(°)	(°)	(lb)	(in)	(s)		
20	20	20	1	1	166.7	5000	3511.3	12	0.75	5	12	30	-30	100	12	1	0.02	2
		Must not exceed length of L1					Cylinder Piston Net Area	112.7	in^2			Angle must satisfy cell D16 with a Pass, or angle is too great			(K)			(K)
							Pipe Flow Area	113.10	in^2						100			30

Outputs

Outlet Flow	Volum e of water in riser pipe	Vertical Travel of W - H_d	Piston Stroke - h_c	Outlet Water Weight	Min. Water Height - H_d	Min. Fulcru m Height - H_1	Time at Which Pumpin g Starts	Time at Which Pumping Ends	Total Half Cycle Time	Averag e Pumpe d Flow Rate	Water Weight of full tank -F_w	Time to fill tank - T_f	Equivalen t Length of Outlet Piping	Flow Rate		Cycle Time	
(gal/stroke)	(gal)	(in)	(in)	(lb)	(in)	(in)	(s)	(s)	(s)	(GPM)	(lb)	(s)	(in)	Time	Flow Rate	Tim e	Flow Rate
58.52	29.38	240.0	120.0	244.70	240.0	120.0	1.00	2.0	2.0	1755.6 7	1388.3	2	2940.0	0	1755.6 7	2.0	0
		(ft)	(ft)		(Ft)	(Ft)	(min)	(min)	(min)	13.52		(min)	(FT)	180	1755.6 7	2.0	1943.7 1
		20.00	10.00		20.00	10.00	0.017	0.03	0.03			0.03	245.00				

Figure 3 Data derived from a portion of the spreadsheet model