Experience and outcomes of a mine water pumping test including temporary High Density Sludge treatment at Thorpe Hesley, Yorkshire, UK

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Abstract

Modular, high density sludge (HDS) treatment was chosen to meet permitted discharge limits during a six month pumping test at Thorpe Hesley, Yorkshire. Modular HDS treatment was favourable because it was temporary, with a relatively small footprint and the resilience to treat significant changes in iron content. Pumping successfully controlled water levels within a 3.5 km radius and provided chemical data to allow the design of a passive treatment scheme. Innovative solutions to challenges were required for this novel approach to treatment. Lessons learned will benefit future pumping tests where treatment of total iron is required under similar constraints.

Keywords: Pumping test, temporary treatment system, high density sludge, mine water treatment

Introduction

Thorpe Hesley, South Yorkshire, was the site of Smithywood Colliery (active 1886–1974), situated to the east of Chapeltown, South Barnsley, (Figure 1). Mining undertaken at Smithywood colliery was relatively shallow and abandoned earlier than deeper collieries to the east. Most of the water reaching the deeper mines of the South Yorkshire coalfield was from recharge waters in the shallow area to the west of Thorpe Hesley. Thorpe Hesley was retained by the National Coal Board as a pumping station to intercept the water flowing eastwards towards the deeper mines such as Kilnhurst (Figure 1). Pumping from shallower depths at Thorpe Hesley, rather than from the deeper mines, was justified because of the lower capital and operational costs and better water quality having shorter residence time in the workings. Pumping ceased at Thorpe Hesley in 1988.

Since cessation of pumping, the mine water levels have been monitored. Mine water in the shallower mining area surrounding the village of Thorpe Hesley is considered to have completely recovered, there are no known risks within this area. Instead the risks associated with mine water rise are related to the contribution to the recharge of the deeper mine waters to the east.

Coal Authority hydrogeological investigations concluded that complete recovery of water levels in the deeper mining area to the east would result in a major surface discharge via the Kilnhurst pumping shaft located in a low lying position within the Don Valley that would subsequently reach the River Don via the Kilnhurst Cut of the Sheffield and South Yorkshire Navigation (canal). Also, if levels rise sufficiently, saline mine water would intrude into a Principal Aquifer within Cadeby Formation bedrock that overlies the coal measures and is currently exploited as a major source of drinking water. Based on the rising mine water trend at Kilnhurst there is a need to have gained control of mine water levels by 2030.

To mitigate the identified risks of mine water recovery in the deeper mining area to the east of Thorpe Hesley a pumping test was proposed. Thorpe Hesley was an ideal location and chosen because the pumping station was historically effective at controlling mine water levels and therefore it was expected to have good connectivity into wider mine workings; it is located to the east of recharge waters and therefore pumping would intercept mine water travelling eastwards towards the deeper mine waters. The site is owned by the Coal Authority and a pumping test could therefore commence relatively quickly without the need for lengthy land purchase negotiations.

Pumping commenced in November 2021 and the test ran for six months. Key objectives were to:

- Confirm the connectivity of the wider workings and determine the effectiveness of pumping at the site in controlling mine water levels;
- Record the flow rates required to control mine water rise;
- Monitor and record mine water chemistry over the pumping test to feed into a permanent treatment design.

Mine water sampling undertaken from No.2 shaft at Thorpe Hesley in May 2018, provided the parameters used to predict mine water chemistry (Table 1). Treatment choice was based on the results of this sampling. However, uncertainty surrounded potential changes to mine water quality during the pumping test and there was a possibility that iron concentrations could double (at least).

Iron concentration recorded in the shaft was too high (≈ 15 mg/L) to release to a small brook that had been designated as the discharge location due to a sensitive receptor, Morley Ponds, (a series of commercial angling ponds), ≈ 800 m downstream of discharge. Therefore treatment prior to discharge was necessary to meet the Environment Agency Permit limit of 5 mg/L total iron and 50 mg/L total suspended solids (TSS) in the effluent.

Hydrogeological modelling, undertaken prior to the pumping test, indicated that maintaining a flow rate of 50 L/s during the pumping test at Thorpe Hesley would be sufficient to control mine water levels in the area. This was the maximum rate of discharge permitted by the Environment Agency.

Predicted mine water chemistry, and flows required to control water levels

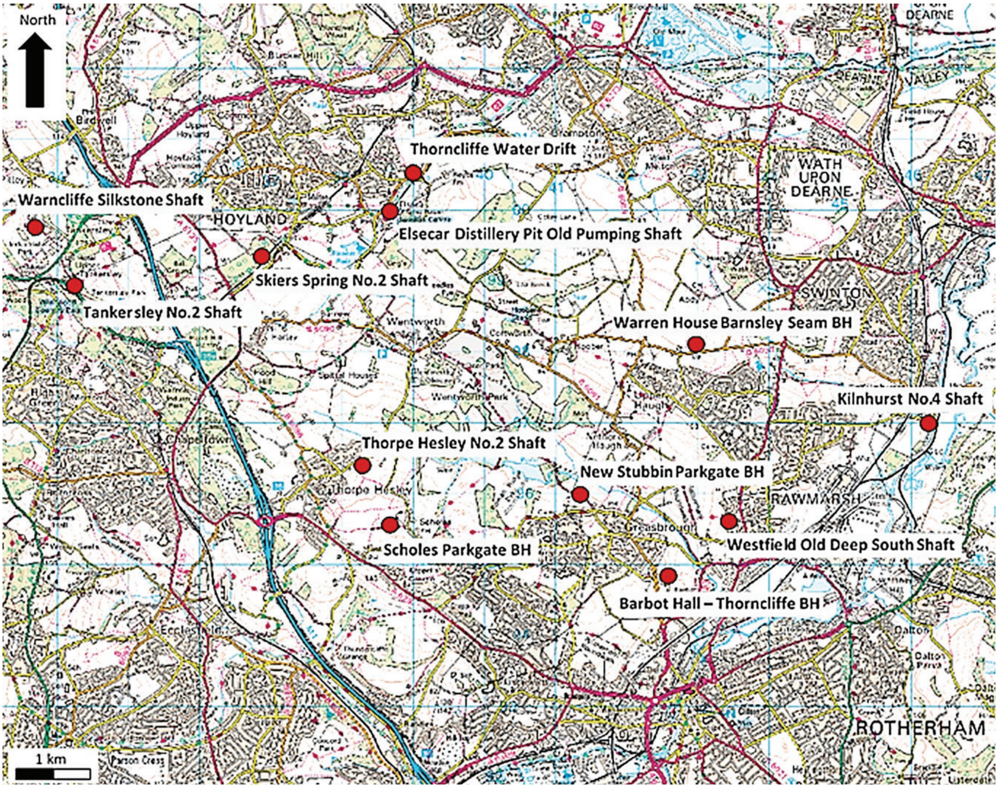

Figure 2 *Water level monitoring sites including Thorpe Hesley No.2 shaft (base map reproduced by permission of Ordnance Survey Licence Number 100020315).*

indicated that a passive treatment scheme was feasible and this is the preferred option long term. However a temporary modular HDS treatment scheme was favoured for the short duration pumping test due to:

- Land availability – procuring sufficient land for a passive treatment scheme would have required lengthy negotiations with the current owners and delayed the programme targets. Whereas the temporary active treatment plant could be built within the footprint of Coal Authority land-holding.
- Planning – some adjacent land areas are green belt land and added significantly to the programme risk of developing a passive treatment scheme at Thorpe Hesley. Whereas, deployment of a temporary active treatment system on existing Coal Authority land was deemed as permitted development.
- Outcome uncertainty – there was uncertainty regarding how effective pumping at Thorpe Hesley would be in controlling water levels within the wider area. Using a temporary active treatment system meant should the pumping test not be fully successful system could be relocated.
- Mine water quality variation – there was the potential for significant mine water quality variation during the pumping test. Active treatment processes are more resilient to significant changes in iron content in the mine water than passive treatment processes.

Temporary modular high density sludge (HDS) treatment system design

JN Bentley Ltd, the principal contractor assigned by the Coal Authority, sub-contracted Siltbuster Ltd to design and build a temporary HDS treatment system. The process plant and equipment, supplied by Siltbuster, was housed in shipping containers. The treatment plant occupied an area of ~700m^2.

Mine water was pumped from No.2 shaft via a borehole pump mounted 75 mBGL. Flow rate varied between 10–15 L/s at the start of the pumping test, to allow a period of treatment adjustment and calibration, and increased up to a maximum of 50 L/s. A two stream treatment system was used each stream treating up to 25 L/s flow (Figure 3). This approach to operating meant the plant could run at minimum required capacity potentially saving on the operational costs of running large mixers in low load conditions and enabled continuity of treatment if one stream encountered operational issues.

Treatment was designed to oxidise up to 100 mg/L dissolved iron, and precipitate it as iron oxyhydroxide, resulting in an effluent water containing < 3 mg/L total iron. Each treatment stream had a MT100 mix tank

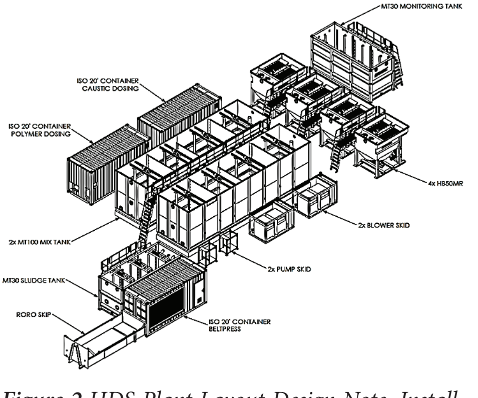

Figure 2 *HDS Plant Layout Design Note. Install. included a plate and frame press, not a belt press.*

Figure 3 *Containerised Temporary Plant Setup (stream A right, stream B left of photo)*

Table 1 *Shaft mine water chemistry (180 mBGL) (prior to pumping test) and Pumped mine water chemistry (raw and treated)*

Analyte	Pre-pumping	Pumped mine water (Raw)						Pumped mine water (Treated)					
	Shaft sample	Mean	Max	Min	Std. Dev.	90th Percentile	Count	Mean	Max	Min	Std. Dev.	90th Percentile	Count
Iron, Total (mg/L)	14.8	11.39	16	7.77	1.60	12.86	50	1.13	3.49	0.01	0.82	2.25	50
Iron, Dissolved (mg/L)	13.9	10.44	14.1	6.28	1.42	11.4	48	0.08	0.68	0.01	0.14	0.17	50
Chloride (mg/L)	110	84	102	71	6.04	90	50	90	116	72	7.24	95	50
Sulfate (mg/L)	991	1,017	1,160	904	59.98	1,090	51	1019	1150	907	59.86	1091	50
Manganese, Total (mg/L)		1.24	1.52	0.84	0.11	1.38	51	1.21	1.51	0.98	0.11	1.34	50
*Manganese, Dissolved (mg/L)		1.25	1.57	0.83	0.12	1.43	51	1.21	1.53	0.98	0.11	1.31	50
Alkalinity, as Calcium Carbonate (mg/L)	573	569	655	467	38.69	602	51	668	819	523	67.25	744	51
pH	7.0	6.48	6.97	6.00	0.21	6.19	157	7.02	8.1	6.25	0.37	6.75	157
Conductivity µS/cm	3070	2,910	3,165	2,679	81.25	3,004	157	3010	3285	1674	163.04	3172	147
Temperature °C	14.6	13.0	17.3	10.2	1.1	14.1	156	12.58	16.55	9.25	1.31	13.99	156

*Dissolved manganese is higher than total, but within analytical error of the instrument.

that combined the mixing and pH adjustment stages. In the first section mine water mixed with the re-circulated ochre sludge. The resulting mixture flowed into the second section where 20% w/w sodium hydroxide was added to raise the pH together with aerial oxidation via a blower system.

Hydraulic retention time (HRT) of water in the MT100 mix tank was ≈ 80 minutes whilst running at 25 L/s. An anionic polymer was added to encourage flocculation as the water passed through to two lamella tanks (HB50MR Settlement Units) for settlement of the solids.

Settled sludge was expected to have a dry solids content of ≈ 12% w/w. Sludge was then either re-circulated to the first section of the MT100 mix tank at a mass ratio of 50:1 total iron oxyhydroxide concentration in the mine water, or pumped to a plate and frame press capable of producing a dry solids content of up to 45% w/w.

Following clarification the treated effluent from both streams was directed to a baffled monitoring tank with a Programmable Logic Controller system set to recirculate treated mine water back to shaft if TSS exceeded 25 mg/L (50 mg/L at the start of the pumping test) and/or pH went out of permitted range (pH 6 to pH 9).

Hydrogeological and geochemical findings – summary

Pumping at an abstraction rate of 50 L/s resulted in a maximum drawdown of 5.55 m within Thorpe Hesley No. 2 shaft. Over a wider 3.5 km radius from Thorpe Hesley (Figure 1), pumping was found to control the water level at two sites, New Stubbin, located ≈ 3 km east, and Skiers Spring just under 3.5 km north west, of Thorpe Hesley No.

2 shaft. Water levels were not controlled at Scholes Parkgate despite it being the closest monitoring site to Thorpe Hesley. This is likely due to poor hydraulic connectivity within the workings. Overall influence of pumping at Thorpe Hesley on water levels over a radius wider than 3.5 km was uncertain and longer term pumping (over years) would be required to confirm control.

Hydrogeological drawdown, through pumping at Thorpe Hesley, was found to align with previous predictions for Thorpe Hesley, by intercepting mine water before it migrates to the deeper mine workings to the east. Therefore it was recommended that long term mine water treatment options were explored to enable continued pumping at the site.

Water monitoring was undertaken at four locations, from the inlet pipe prior to treatment (raw mine water), the monitoring tank (treated mine water), 20 m downstream from discharge and at Morley Ponds (a downstream sensitive receptor).

Results from the raw mine water monitoring indicated there was no major variation in mine water chemistry in response to flow rate change (Figure 4). Average total iron was 11.4 mg/L of which ≈ 90 % was in dissolved form (Table 1). A maximum of 16 mg/L total iron was recorded on three occasions while pumping at 50 L/s. Total suspended solids were generally quite low (15.9 mg/L average). Throughout the trial raw water pH remained ≈ pH 6.5. Mine water was net alkaline and sulfate and chloride showed no variation in response to pumping rate. The high percentage of dissolved iron and sulfate concentration in the mine water are reflective of partial pyrite weathering within a limited oxygen environment (Younger *et al.* 2002). The net alkaline waters served to buffer acidity and maintain a circum neutral pH. The raw mine water chemistry results indicated that treatment through a passive scheme was feasible.

HDS treatment successfully oxidised the mine water and raised the pH (Table 1). Average total iron and TSS concentration in the effluent water was 1.13 mg/L and 10 mg/L respectively. Treated mine water remained below the Environment Agency permitted discharge limit of 5 mg/L total iron

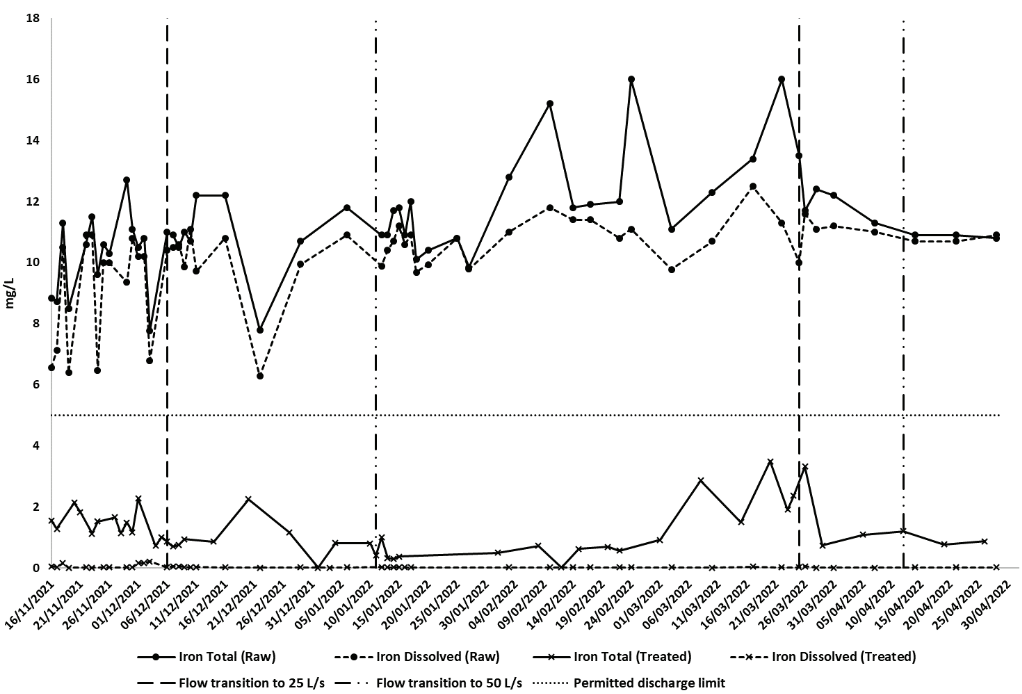

Figure 4 *Total and dissolved iron concentration in the raw and treated mine water in response to flow transitions.*

and 50 mg/L TSS throughout the pumping test. Results of water sampling undertaken at Morley Ponds indicated the treated mine water discharge did not impact water quality at that location.

Discussion (challenges and learnings)

Whilst the pumping test was successful in meeting the key objectives of the project, there were a number of challenges during the operation of the plant. The Coal Authority have experience of operating permanent or long term temporary HDS installations. However this was the first time it had used a containerised temporary HDS plant to support a pumping test.

Site specific adjustments were required to improve treatment performance when the plant was commissioned. Initially the fines in the lamella tank were not settling sufficiently for the ochre sludge to reach the optimum 12% w/w dry solids content. This hindered the re-circulation of ochre sludge to encourage further iron oxyhydroxide precipitation. Whilst the total iron content of the mine water was too high to discharge without treatment, it was too low for treatment using a high density sludge system. Ferric chloride solution was added to the MT100 mix tank to 'seed' the mine water and encourage iron hydroxide formation. Dry solids content of the ochre sludge increased and performance improved.

During commissioning the TSS alarm was triggered in the monitoring tank and water was discharged back down to shaft. Jar tests demonstrated that the sludge going to the clarifier contained two phases; an iron high density sludge that settled quickly and a 'haze' containing fine calcium carbonate crystals and 2–3 mg/L total iron. The latter was an issue because it exceeded the agreed internal site specification of 3 mg/L total iron in the discharge, but not the Environment Agency permitted limit of 5 mg/L. Prior to this the plant operated at > pH 8.4 to precipitate as much iron oxyhydroxide as possible and the sludge density was 1035 kg/m3. The operating pH was changed to pH 8, the sludge density decreased to 1020 kg/m3. Further tests showed that the treated water contained calcium ions which contributed to the observed calcium carbonate haze. At > pH 8.4 the calcium carbonate precipitated as much larger crystals that collected in the sludge. To rectify the situation the plant was run at ≈ pH 8.7, with the aim of precipitating calcium carbonate and flocculating it to form larger crystals that settled. The plant was run for 48 hours in this mode and when total iron and TSS concentrations were below internal discharge limits the treated water was discharged to stream. With sufficient high density sludge recirculated to collect the calcium carbonate the plant remained at pH < 8 for the duration of the pumping trial.

For the first three months the site was powered by a 415 V generator due to delays connecting to the electricity grid. At the time the COVID-19 pandemic was on going and it was during a period of fuel shortages. So measures needed to be taken to ensure sufficient supply of diesel particularly during sensitive periods. A second generator was installed to mitigate power loss and subsequent plant shut down especially over the Christmas holiday period.

In order to assess water level recovery rates, instantaneous changes in flow were needed. Increasing or reducing the flow rate required a period of calibration and dosing adjustment to optimise treatment. Therefore it was not possible to instantaneously modify chemical treatment. This meant that the water team, chemistry team and on site contractor needed to work in close association to accommodate all needs. At times compromises were made.

Conclusions

Novel, temporary, modular high density sludge (HDS) treatment carried out during a six month pumping test at Thorpe Hesley, Yorkshire was found to successfully control water levels within a 3.5 km radius and provided chemical data to allow for the design of a passive treatment scheme at the site.

HDS design included two streams each treating up to 25 L/s raw mine water and up to a maximum of 100 mg/L iron (although total iron concentration did not exceed 16 mg/L). Water chemistry was not found to vary in response to flow rate. Treatment was successful and discharge waters remained within permitted consent limits of 5 mg/L total iron and 50 mg/L total suspended solids and the sensitive receptor Morley Ponds was not affected. Innovative solutions to challenges were required, particularly during commissioning and due to the ongoing COVID-19 pandemic. Lessons learned will benefit future pumping tests where treatment of total iron is required under similar constraints.

References

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