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Review

Hellfire Exploration: the origins of ground source heat in early mining technology

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Abstract

The ground source heat pump (GSHP) was first used in 1862, for freezing ground in connection with sinking a shaft in Swansea, UK. It was subsequently developed in Germany in 1882-83 into the "Poetsch process" for freezing ground during construction of mine shafts. The Poetsch process was an indirect closed loop GSHP system, circulating a chilled brine from a heat pump around a network of coaxial borehole heat exchangers. These early systems typically employed ammonia as a refrigerant and a calcium or magnesium chloride solution as the brine. Such a system was used in 1904-1906 to sink the shafts of Dawdon Colliery, Co. Durham, UK through water-bearing Permian strata. Also, around 1904, the Newcastle-based turbine pioneer, Charles Parsons, suggested that such a GSHP system could transport heat to the surface during the construction of a 12 mile deep "Hellfire Exploration" shaft, that could potentially access geothermal power.

Keywords: Ground freezing, ground source heat pump, coal mine, mine shaft

1. Introduction: Paul Younger's contribution to geothermal and mine water research

This special issue celebrates Professor Paul Younger's career and his substantial contributions to promoting awareness of the environmental legacies of abandoned coal mines and research on unconventional energy sources from the earth.

Much of the central portion of Paul's career in hydrogeology was devoted to dealing with the consequences of large-scale closure of underground coal mines throughout the UK in the 1980s and 1990s, and especially in the north-east of England [1,2]. He engaged in applied research to understand how the mine water that flooded into abandoned mines could be managed, the origins of its characteristic hydrochemistry [3,4], its treatment [5] and the application of models to evaluate management strategies [6,7]

Later in his career, Paul's interests turned to the looming energy crisis, and the fundamental changes necessary in our attitudes to energy supply and consumption if we are to avoid the worst consequences of anthropogenic climate change. Paul was among the early advocates of a renaissance in geothermal energy in Britain [8,9], being instrumental in drilling two new deep geothermal exploration boreholes in Weardale [10,11] and central Newcastle [12]. He recognised the benefits of ground source heating and cooling [13,14] and was keen to explore unconventional uses of the UK's coal resource, such as underground coal gasification [15]. Above all, he was a talented and sympathetic communicator of energy policy. His inaugural lecture at Glasgow was a thing of beauty – extolling the virtues of pumped energy storage inside the Scottish mountain Ben Cruachan in song [16]. He engaged with student advocates of fossil fuel divestment; he was sympathetic to their aspirations but – in the kindest way possible – urged them to consider the realities of our likely energy future [17]. He also produced a popular handbook on Energy, which deserves to be read by every politician, activist and researcher in the field of renewable energy [18].

Moreover, Paul loved to communicate science and technology via history, using old mining tales to illustrate the strategies used to control and manage underground waters [19]. He was a fluent Gaelic speaker and passionate about his Tyneside heritage. It is thus appropriate that this paper starts with the Newcastle-based, Anglo-Irish engineer Charles Parsons, who was among the first scientists to propose the use of a subsurface closed loop ground source heat pump system as a means of extracting the earth's geothermal heat. The paper ends with a case study from the Durham coalfield, not far from Paul's birthplace.

2. Charles Parsons and the Hellfire Exploration Project

Charles Algernon Parsons (Figure 1) was born in London in 1854 to an Anglo-Irish family with its roots in County Offaly. Early in his career, he moved to Newcastle, England, working first for the engineering company W.G. Armstrong and later the ship engineers Clarke, Chapman & Co., where between 1884 and 1887 he pioneered the steam turbine engine, which became widely utilised both in electricity generation and marine propulsion. In 1889 he founded his own engineering company in Newcastle to produce these turbines [20,21].

Figure 1. Portrait of Sir Charles Parsons from image collection of the Smithsonian Libraries (https://library.si.edu/image-gallery/73468) (public domain, CC0 licence).

In 1904, Parsons addressed the British Association for the Advancement of Science (BAAS) on the topic of invention [22]. His lecture was wide-ranging but broadly discussed the roles of the scientist and engineer in technological progress, and the obstacles presented to such progress by risk aversion, imperfect patent law and the challenges of mustering capital. As an example, he cited the potential benefits of exploring the deep earth's crust (at the time, the deepest shaft or borehole was around 1 mile deep). Parsons noted that the construction of a 12 mile deep shaft could plausibly be accomplished within an 85 year time frame with the technology of the time, provided only that the will and capital (an estimated £5 million) were available. He recognised obstacles relating to atmospheric pressure, rock pressure [23] and extreme heat encountered during such a venture and he proposed engineering solutions to these. To keep the excavation cool, he proposed a network of circulating "brine" (heat transfer fluid) pipes, both inside the excavation and through boreholes outside the perimeter of the shaft, connected via staged ring mains to refrigerating engines (heat pumps). He noted that such an arrangement would be "capable of carrying an enormous quantity of heat upwards to the surface", and further noted that the amount of heat would be dependent on both rock temperature and thermal conductivity. In essence, he had effectively a proposed a colossal, closed loop ground source heat pump (GSHP), some 8 years before Heinrich Zoelly's (1912) GSHP patent! Admittedly, in his 1904 paper [22], it is not clear whether extraction of heat or geothermal power was uppermost in Parsons' mind – his main motive was exploration and prospection of Hadean depths.

By 1919, Parsons was addressing the BAAS again, reviewing the scientific progress of the previous two decades [24]. Having considered the future exhaustion of Britain's coal resources and the advisability of developing hydroelectric power, he revisited the idea of the 12 mile shaft. This time he explicitly connected the prospect of deep geological exploration with geothermal power, citing it alongside the Larderello geothermal power plant in Italy. Moreover, Parsons' former apprentice, T.G.N. Haldane, and the latter's colleague, H.C.H. Armstead, were in no doubt that Parsons recognised the geothermal potential of his – arguably somewhat whimsical – proposal and noted that he had dubbed it his "Hellfire Exploration" Project or Company [25–29]. For Parsons, though, it seems that the closed loop heat pump system was merely a means of attaining extreme depths for purposes of scientific discovery or accessing geothermal power – it is not wholly clear that he recognised that the heat transferred to the surface via the heat pump system had any great value in itself (and why should he, in an age of coal combustion and steam engines, when surplus heat was readily available?).

One can speculate where Parsons' idea may have originated from. To this author, it seems highly likely that it may have been grounded in observations from the mining industry – familiar to any inhabitant of Newcastle at that time – that:

- Temperature increases with depth into the earth, and
- Heat pumps had in fact already been used in mine shafts: not for the purpose of supplying heat, but rather for freezing ground to sink shafts through unstable or groundwater-containing strata.

In fact, in his 1904 address [22], Parsons specifically cites the Poetsch process for sinking mine shafts via ground freezing.

3. A conventional history of heat pumps and ground source heat pumps

The heat pump is a device that uses a power input to create and sustain a temperature gradient between a heat source and a heat sink (often, two heat exchangers). The most common variant uses a mechanically powered refrigerant cycle to create a temperature difference between a warm condenser and cool evaporator. The device can thus “pump” heat from any heat source coupled to the evaporator to any heat sink coupled to the condenser.

The heat pump is normally recognised as having been first invented and demonstrated by Jacob Perkins around 1834 [30,31], and further developed into a means of artificial air conditioning and refrigeration by pioneers such as James Harrison, Alexander Twinning and John Gorrie in the subsequent years [30,32–34]. Both Lightfoot [35] and Schmidt [36] give excellent overviews of refrigeration technology towards the close of the 19th Century. In those early years, the condenser (warm) end of the heat pump was regarded as largely uninteresting; after all, anybody could create heat by setting fire to a pile of coal, peat or wood. The "cold end” was the interesting component, because it permitted for the first time efficient artificial refrigeration on demand, at a time when the alternative was importing blocks of ice by sea from North America or Scandinavia [31,37]. It was not until 1852 that William Thomson (Lord Kelvin) suggested that a heat pump device could be used to extract heat from the atmosphere and use it to heat a building (Queens College in Belfast was his preferred candidate, but it seems the device was never built [38,39,40]).

A ground source heat pump (GSHP) is simply a heat pump that extracts heat from the ground (via the evaporator) and delivers it at a heat sink, typically at the surface (such as a central heating system). Modern closed loop GSHP employ either

- a direct exchange (DX) system with a buried evaporator (coils of refrigerant pipe), or
- an indirect system – comprising buried pipework (“ground loop”) containing circulating secondary heat transfer fluid, thermally coupled to the heat pump evaporator. This is by far the most common variant in modern GSHP.

In both cases, the “ground loop” is typically buried in shallow trenches or deeper boreholes. Conventional wisdom has it that the GSHP concept was first patented by Heinrich Zoelly in 1912 [31,41–44], but the idea appears to subsequently have lain unused for years or decades.

Water-sourced heat pumps (evaporator extracts heat from surface waters: river, lakes or the sea) were, however, developed in the 1920s and 1930s. The innovator T. Graeme Haldane (who had been an apprentice at Charles Parsons’ firm) installed a water-sourced heat pump at his house at Foswell, Perthshire, Scotland (Figure 2) in the mid-1920s [28,45]. It seems likely that the water supply for the heat pump was groundwater derived from springs, making this a candidate as one of the earliest groundwater-sourced heat pumps.

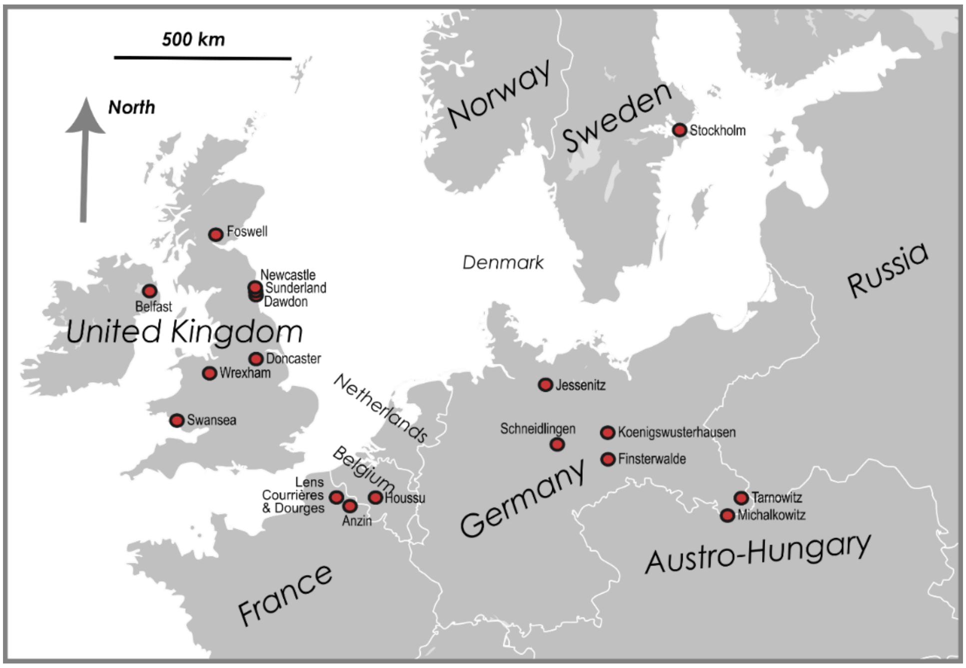

Figure 2. Map of Europe showing political boundaries in 1890, and locations of sites named in text. Modified after an svg map by Alphathon [46] (released under a CC BY-SA 3.0 licence).

The first closed loop GSHP is commonly regarded as that constructed by Robert Webber of Indianapolis, USA, in 1945. He buried 152 m of Freon-containing refrigerant pipework (the evaporator) in 36 m of trenches at a depth of 1-2 m and succeeded in delivering warm air at around 43°C and a coefficient of performance of 3.61 [43,47–51]. In Great Britain, such GSHP systems were trialled and promoted in the 1940s to 1970s by Miriam Griffith [52] and John Sumner [53] and in Northern Ireland by Goulburn & Fearon [39].

This paper will, however, argue that the first closed loop GSHP significantly predated Zoelly's (1912) patent. In fact, they had already been used in the mining and construction industry for several decades: not to supply heat, but rather to freeze the ground, permitting subsurface construction.

4. Ground freezing

The current technology of ground freezing in the context of shaft sinking or subsurface excavation is comprehensively described in Harris's textbook [54]. The purpose of ground freezing is both to stabilise water-bearing ground and to prevent the ingress of water from running sands or other aquiferous strata during excavation or tunnelling [55,56]. It was often used to construct mine shafts through the water-bearing Triassic Sherwood Sandstone or basal Permian sands which overlie the Coal Measures across much of the UK's concealed coalfield. Subsequently, ground freezing has also been recognised as having potential in containing or even treating hazardous waste sites [57,58].

Currently, two methods are commonly employed [54,57,59]:

i. The cryogenic method, where a shipment of liquid nitrogen or carbon dioxide is sourced externally and circulated through pipes emplaced in the ground around the shaft or other volume of ground to be excavated. Liquid N_2 evaporates in the buried pipes at around −196 °C, freezing the surrounding ground, and then exhausts to atmosphere. This method can freeze the required ground in less than 1 week.

ii. The brine method, which employs on-site refrigeration equipment to chill a solution of saline anti-freeze to sub-zero temperatures (−20 to −40 °C), which is then circulated around the pipe system. This method usually takes 3–12 weeks to adequately freeze the ground so it can be excavated. This is sometimes referred to as the Poetsch method.

Only the second of these two options can be considered a ground source heat pump (GSHP), so discussion will be limited to this method.

In modern ground-freezing systems [54], the brine is typically a calcium chloride solution of specific gravity 1.24 to 1.28 and circulates at below -20 to – 40 °C. Where especially low temperatures (lower than −40 °C) are required, lithium chloride can also be used. The pipework usually consists of steel coaxial closed loop boreholes (or “freeze tubes”) in a CXC configuration – whereby the chilled brine descends via a central coaxial tube and then returns to the surface via the external annulus (CXC = CoAxial, flow down Centre [60,61]). This configuration ensures that the coldest brine temperatures are applied to the greatest depths. Occasionally, where it is more important to obtain a greater ice thickness in the upper portion the ground, the reverse flow direction (CXA = CoAxial, flow down Annulus) may be used. Pipe diameters are such that turbulent flow occurs in the annulus (maximising heat transfer from the ground) and laminar flow in the central tube (minimising hydraulic resistance). The bored pipes around the excavation are usually connected via some form of ring main to ensure equal pressure and temperature loss across all bores [54]. At the surface, the returning brine from the return ring main passes through the evaporator of a heat pump (refrigeration unit), where it is chilled to be recirculated to the ground.

The refrigerant plant typically employs ammonia or fluorinated hydrocarbons as the refrigerant, and the condenser sheds heat to an evaporative cooler.

A third (direct circulation or DX) method has occasionally been used [54], whereby the refrigerant is circulated directly via the freeze tubes, evaporating in the ground before returning to the compressor unit.

5. Historic use of ground freezing

Engineers and miners had long taken advantage of excavating naturally frozen ground in winter to ensure stability, especially in Siberia, where fire was often employed to melt and excavate specific portions of otherwise frozen winter terrain [36]. The earliest reported use of a heat-pump for ground freezing was in Swansea, South Wales, UK in 1862 [62,63]. Chilled fluid was circulated via spiral coils of pipe laid on the base of a shaft, to freeze a basal layer of water-bearing ground. Having excavated the frozen ground, the freezing coils could be re-laid deeper, allowing excavation to progress [62]. Most accounts [64] suggest that the Swansea shaft was a (coal) "pit shaft" and, given the rich colliery heritage of South Wales, this seems likely. One early report from 1895 [65] indicates that the "extraction shaft" was sunk in running water-bearing sands ("*un puits d'extraction dans des couches de sables inconsistants et aquifères voisines de la surface"*) – most likely a coal shaft, but plausibly a water well. The company Siebe, Gorman & Co. of London reportedly provided a refrigeration machine based on an ether refrigerant cycle, probably of the type described by [32,66]

The process was improved by the German Friedrich Hermann Poetsch [67,68], who introduced the modern method of drilling holes around the circumference of the shaft, and circulating the chilled fluid through vertical pipes emplaced in the holes. He first employed the technique in around 1882 [69,70] by installing coaxial freeze pipes into 23 boreholes drilled around the circumference of the 34 m deep Archibald shaft (Schneidlingen, Sachsen-Anhalt, Germany) to allow a water-bearing sand to be penetrated and a seam of coal reached at 39.5 m. The refrigeration was supplied by a Carré-Kropff ammonia absorption heat pump via a circulating calcium chloride heat transfer fluid [36]. Poetsch obtained a German patent in 1883 [71] and an American patent in 1884 [72]. He also produced a comprehensive monograph [73] describing the technique: this recognised that any type of heat pump could, in principle, be used to chill the heat transfer fluid, but described in detail a system using a Carré-Kropff-type ammonia absorption heat pump and a circulating magnesium chloride solution down coaxial borehole heat exchanger (BHE) pipes in a CXC arrangement. In his 1887 USA patent [74], Poetsch goes beyond the concept of coaxial BHE as freeze pipes, and describes U-shaped pipes embedded in cement grout within a borehole (essentially, the most common arrangement of BHE used in modern GSHP systems for heat provision).

Thus, the Poetsch process of ground freezing using a GSHP and coaxial drilled borehole heat exchangers became recognised in Germany [36,62,65] and was much discussed internationally [75–78]. After the Archibald shaft experience, the Poetsch technique was used (not always without problem) throughout the 1880s at the Max-mine near Michalkowitz, Silesia (modern Michálkovice, Czech, Republic), at the Centrum lignite mine at Koenigswusterhausen near Berlin, at the Emelie coal mine near Finsterwalde [79], at the Houssu coal mine (Hainaut, Belgium), at the rock salt mines in Jessenitz (Mecklenburg-West Pomerania, Germany) and (in 1890) at the Georgenburg iron mine of Tarnowitz (Tarnowskie Góry, Poland) [36,54,65].

In 1888–89, the method was applied at the Chapin iron mine in Michigan, USA, using a Linde heat pump [78,80]. It was also employed in France at coal mines in Lens, Courrières and Dourges in the Nord-Pas de Calais coalfield in the period 1891–1893 [36,65]. These early ground freezing projects were typically employed on shafts < 100 m deep.

In 1887, the technique attracted the attention of the owners of the Anzin coal mines in northern France (immortalised by Zola in his novel *Germinal* – [81]). Saclier & Waymel [65] give a highly detailed description of using the Poetsch process in 1894 to sink the two Vicq shafts (3.65 m and 5 m in diameter) to eventually reach Carboniferous strata below a *ca.* 188 m thick cover including Cenozoic strata, Chalk, marls, and greensand. Schmidt [36], however, suggests that the section over which freezing was employed was some 102 m and that the coaxial (116 mm outer ID and 30 mm inner ID) coolant tubes were 92 m deep. An ammonia-based Linde heat pump, and calcium chloride brine as heat transfer fluid were employed.

6. Early ground freezing in construction

The applicability of ground freezing in other construction works (tunnels, quays, canal locks) was recognised early on [36]. In the 1880s, it was used in the construction of a 230 m pedestrian tunnel though a hill near Lake Mälaren in Stockholm [36,82]. The tunnel proceeded along the interface of sands and gravels overlying granite bedrock. Water inflow through the superficial materials, mobilising sediment, led to a ground freezing process being employed in a 24 m section of the tunnel in 1886. A Lightfoot air expansion heat pump was used to supply chilled air to a sealed tunnel section, freezing the gravels and allowing excavation to continue.

7. Early ground-freezing technology

In 1895, Schmidt [36] reviewed the state of the technology employed in the still-young ground-freezing Poetsch process. He considered the use of absorption (Carré) heat pumps, air-relaxation (Lightfoot) heat pumps and the compression-expansion heat pumps more familiar to modern users (Figure 3). In the last type, he considered the use of diethyl ether, sulphur dioxide, methyl ether, carbon dioxide and ammonia as refrigerants. He noted that several of the earlier ground freezing projects were accomplished using Carré-Kropff absorption heat pumps, but he himself preferred a Fixary ammonia compression-expansion heat pump machine.

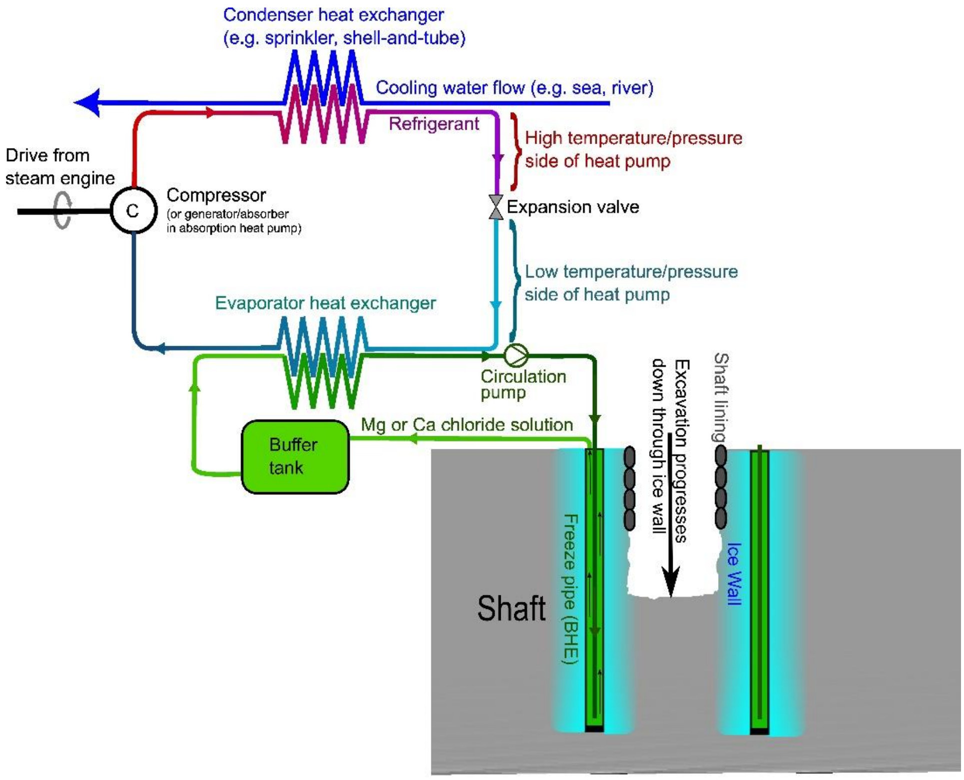

Figure 3. Schematic diagram of early ground-freezing apparatus (see, for example [62,71,73]. In a modern plant, the compressor would often be electrically powered and the heat exchangers might be plate heat exchangers. In several of Poetsch's early systems, an ammonia absorption heat pump (*i.e.*, thermal "compression" of refrigerant, rather than mechanical, as shown above) was used.

An alternative to the Poetsch method, the Gobert method, was noted by [36], where liquid ammonia refrigerant circulates directly through refrigerant pipes surrounding the shaft (an early DX GSHP) and evaporates in the ground, absorbing heat. The extent to which the Gobert technique was actually employed is unclear. Another DX alternative, the Koch method, envisaged the refrigerant being allowed to expand and evaporate at the surface, with the chilled refrigerant gas being circulated (arguably more practical, but not making efficient use of the latent heat of evaporation of the refrigerant).

8. A case study of ground freezing by GSHP at Dawdon, UK

Following the early pioneering Poetsch-type ground freezing projects [36,65], the technology spread around the world. Among the early ground freezing projects carried out in the UK were those at Washington Glebe colliery, near Sunderland in 1902 [19], Wearmouth Colliery 'C' shaft (Sunderland) in *ca.* 1906 [54,83,84], two shafts at Bullcroft Colliery (Doncaster) in 1910 [54] and a shaft sinking a few years later at Llay Main Colliery, Wrexham, to *ca.* 72 m [64].

It is, however, worth focussing on possibly the earliest well-documented instance of coal mine shaft sinking in the UK facilitated by ground freezing – that of Theresa and Castlereagh Shafts at Dawdon Colliery, Seaham, County Durham [85]. UK Coal Authority records [86] show the Theresa shaft at 6.1 m diameter and eventually reaching 532 m deep, at grid reference 54°49'23.7"N 1°19'23.7"W. At this location, the Carboniferous Coal Measures are concealed by a cover of Permian rocks, namely, in descending order: the Magnesian Limestone (*ca.* 109 m), Marl Slates (1 m) and Yellow Sand (28 m). The Magnesian Limestone is a major aquifer, while the Yellow Sands is also water-bearing and can have the nature of quicksand. Considerable difficulty had been experienced sinking mine shafts through these strata in the region [85]. [Note that, in modern stratigraphic terminology, the Magnesian Limestone is now subdivided into the Roker, Concretionary Limestone, Ford, Raisby and basal Marl Slate Formations, while the Yellow Sands is formally the Yellow Sands Formation].

Sinking of the Theresa Shaft and the adjacent Castlereagh Shaft commenced in 1900. The Theresa shaft was sunk through the Magnesian Limestone to 107 m and the Castlereagh Shaft to 62 m, by means of pumping and lining with brick and cast iron. The Castlereagh Shaft was linked by a borehole to a drift from the adjacent Theresa Shaft to allow water drainage from one to the other. The pumping equipment installed in each shaft had a capacity of *ca.* 530 L/s. Huge amounts of water were encountered from the Magnesian Limestone, approaching the pump capacity. The mine company was reluctant to progress further into the Yellow Sands, with the likely large additional water make that would be incurred. Eventually, ground freezing was decided upon and pumping stopped in 1902. The ground freezing project, operated by the German firm, Gebhardt & Koenig of Nordhausen, commenced in 1903, with the objective of sinking the shafts through to a depth of 147.5 m (just below the top of the Coal Measures at 141.45 m bgl). Boreholes would be drilled around the shaft for coolant pipes and an annular ice wall would be established around each shaft [85] (*i.e.*, the Poetsch process – see Figure 4).

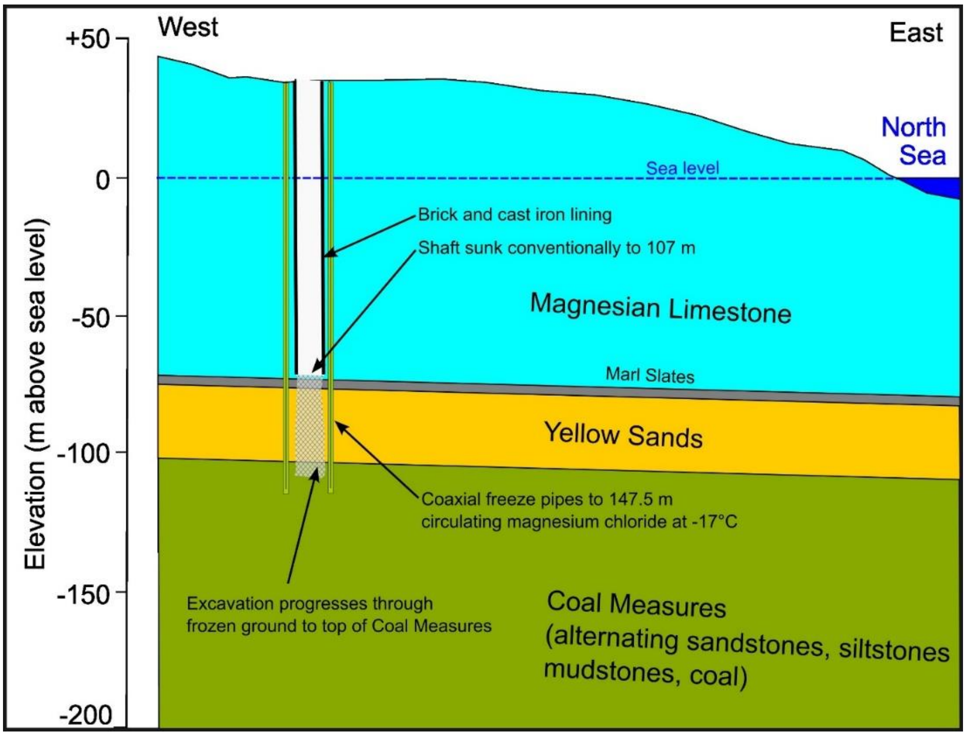

Figure 4. Schematic section illustrating excavation of Theresa shaft at Dawdon (superficial geology ignored).

Twenty-eight boreholes, to 147.5 m, were drilled around each of the two shafts in a circle of 9.1 m diameter (*i.e.*, around 1.5 m outside the shaft perimeter), and lined at 159 mm diameter. The coaxial coolant pipes inserted in the boreholes comprised an outer tube of 5" (127 mm) diameter, an inner tube of 2½" (63 mm) diameter to within 10 m of the base of lining, or "tubbing", in each shaft) and a 32 mm central pipe. This three-tube arrangement allowed coolant to be diverted up the intermediate annulus near the base of the existing shafts, leaving an air space in the outer annulus, preventing excessive frosting of the shaft tubbing. Once the coolant tubes were installed, the borehole liners with withdrawn [85].

The refrigeration was provided by ammonia-compression-expansion heat pumps, with four compressors, driven by two steam engines, and a total cooling capacity of 580 kW. The condensers were cooled by pumped sea water. The circulating coolant (brine) was a 27% solution of magnesium chloride at a nominal temperature of −17 °C and rate of 25 L/s [85].

Freezing of the Castlereagh shaft commenced in April 1904 and of the Theresa shaft in June 1904. The ice wall took 185 days to form in the former and 392 days in the latter (due to persistent water leakage to the shaft). Once the ice wall was established, shaft sinking could progress, with widespread use of shot blasting in the Magnesian Limestone and even in frozen parts of the Yellow Sands. Once the shafts had been constructed into the Coal Measures, the ice wall was unfrozen by warming the brine with steam and circulating it down the coolant pipes. The operations in both shafts were completed by 1906. By 1910, 3300 miners at the colliery were producing 1 million tons of coal per year [87]. The paper by Seymour Wood [85] contains numerous photos of the freezing plant utilised.

9. Full circle: Dawdon GSHP for heating

Dawdon Colliery was productively operated from 1907 to closure in 1991. As the Durham Coalfield progressively closed, the risk posed by the uncontrolled filling of the mine systems with iron- and sulfate-rich mine water was recognised by Paul Younger [1,2,6] and others. A region-wide network of pumping and mine water treatment systems was established to control the rising mine water, of which Dawdon became a part. Theresa shaft is pumped at rates of up to 150 L/s at temperatures of 18-20°C, while the iron in the water is removed by active water treatment at a nearby treatment unit, before being discharged to the sea [88].

Subsequently, in 2011, the Coal Authority decided to trial a pilot heat pump system at the plant [89,90], extracting heat from the mine water to heat the office space at the treatment plant building. Despite some geochemical issues with precipitation of ochre in the heat pump system, the pilot trial eventually proved successful. Currently, a full-scale scheme is proposed to use heat pumps to extract several MW of heat from the pumped mine water, and to use that heat to supply a domestic district heat network for the new Seaham Garden Village development [91,92]. This is certainly an innovative low-carbon heating delivery system, but aspects of it are not completely new – 580 kW coaxial closed loop GSHP systems were already running at Dawdon's Theresa Shaft in 1904.

10. Conclusions

Conventional narratives usually recount the first patenting of a ground source heat pump (GSHP) by Heinrich Zoelly in 1912, and the construction of a working closed loop direct circulation GSHP system by Robert Webber in the USA around 1945. These narratives are concerned solely with the supply of heat from the condenser being used for heating purposes.

However, the GSHP was a fully developed piece of technology already in the latter half of the 19th century. The focus of such early systems was on the ground freezing effect, rather than the heat supplied at surface.

The world's first GSHP was used to assist in sinking a shaft in Swansea, Wales, UK as early as 1862. This ground freezing activity was subsequently formulated as the "Poetsch process" for excavating mine shafts - an indirect closed loop heat pump system, circulating a chilled calcium (or magnesium) chloride brine solution through coaxial borehole heat exchangers. The Poetsch process was patented and applied firstly in Germany in 1882–83 and then in neighbouring countries such as France and Belgium. The process was used in sinking shafts at Dawdon colliery, County Durham, UK, as early as 1904.

Around 1904, the Newcastle-based turbine pioneer, Charles Parsons, suggested that a gigantic closed loop GSHP system could also be used to transfer heat from the ground to the surface and assist in the construction of a 12 mile deep "Hellfire Exploration" shaft. Given the application of this technology for ground freezing at Dawdon (a short distance south of Newcastle) in the same year, Charles Parsons' fantasy "Hellfire Exploration Company" seems far less whimsical than it might first appear, being firmly rooted in the new technologies being introduced in the NE of England at the time.

Despite being an outward-looking internationalist, Professor Paul Younger would no doubt be quietly pleased that a significant piece of GSHP history was likely rooted in minewater management issues so close to his "Geordie" heritage.

Ethics Statement

Not applicable.

Consent for Publication

Not applicable.

Availability of Data and Material

Not applicable.

Competing Interests

The author has declared that no competing interests exist.

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