Review on Dewatering Pumping Network for Underground Coal Mine

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***Abstract*—Underground mine working changes hydraulic gradient which affect the underground surface water flow pattern. It induces slow inflow of water from, porous soil and rock mass towards the mining excavation. Mine dewatering is the removal of percolated or logged water from mines to ensure the safety of operating personnel and to safeguard the machineries involved in excavation. Usually pumps are employed for the purpose of removal of water because of their high economical value and reliability moreover pipeline network is also significant for the fast removal of logged water inside mine. Therefore, an optimize pipeline network is essential.**

Keywords— Underground mine, dewatering, and pumping network

I. INTRODUCTION

Mining of minerals involves excavation below the earth surface. The deep seated mineral that lies below the water table requires pumping activity for carrying out mining operations. In India most of the coal fields are lying near river and are sedimentary in nature. The sedimentary rocks being highly permeable and porous stores enormous amount of water. Hence, water problems are some of the most intractable problems in coal mines. Sometimes it is also found that volume of water flow often exceeds the mass output of the coal. Therefore, it is almost true to say that all mines, at once in their lives, will have problems regarding water [1]. Mines function only because pumps dewater the seepage during mining activity. The need for better control of mine water can be judged by the severity of the recent mine flooding, concern with depth of dewatering and direct and indirect cost of working in watery strata. Dewatering problem persists for discontinued and abandoned mines also [2]. Therefore, pumping network is one of the most important parts of the mining system to be concentrate upon to regulate the pumping process to increase the efficiency and reduction of pumping cost [3]. In this respect, here, a review of literatures have been carried out on different methods of mine dewatering and its challenges, selection of pumps for specific jobs in mines, from its history to the latest developments, pumping schemes, methodologies of piping network and its developments, latest available software for pipe network analysis. Correct estimation of the ground water inflow to the mine workings is very important in designing of the pumping systems. The source of water may be from (i) surface accumulations such as lakes, rivers, seas, oceans, (ii) bed separation and solution cavities, (iii) old mine workings, (iv) open or confined aquifers, (v) subsidence cracks etc. In the following section different methodologies of dewatering are given.

II. EASE OF USE DIFFERENT METHODS OF MINE DEWATERING

Techniques that have been utilized over the years in the dewatering of mines are as follows. (i) Surface control of water, i.e. artificial means of constraining percolation or increasing the runoff rate in any hydrological basin that should have the long-term effect of decreasing the recharge rate in the aquifers. This methods controls surface water include the use of dams, canals and pipelines to carry water over hydrological hazard zones, herringbone ditches to speed up run-off, stream-gauging to locate hydrological hazard zones and quantity flow rates, location of dams and other surficial water structures. (ii) Interception methods, which involve the siting of major underground dewatering centers at the extremities of the mining areas. The centers should be so sited as to intercept the inflow of aquifer water, down the cone of dewatering towards the mine, to prevent the recharge of the aquifers in the mining area. (iii) Simple drainage methods, which is widely used in mines where the pumping capacity is sufficient to handle uncontrollable flows of groundwater. It is probably the simplest and most widely used drainage method throughout the world. It involves the mining of development drives into aquifer zones, where hydrostatic pressures have been previously reduced by dewatering drilling. The theoretically uncontrollable flows of water, induced by the raining, are catered for by substantial pumping capacity and arrangements of watertight doors to protect shaft and other major underground parts of mine. (iv) Breakthrough methods, which involves the mining of drives or crosscuts into aquifers, but in a more controlled manner than in simple drainage. In this process, drives or crosscuts are mined directly into specific aquifers, behind the protection of a water-tight door or puddle pipe installed in the drive or crosscut being advanced. (v) Dewatering drilling, which is divided into surface and underground boreholes. Surface dewatering boreholes may be either pumped, utilizing down-the-hole pumps, drilled into open pit walls to drain aquifers under hydrostatic pressure, or used for piezometric measurements. Whereas, underground dewatering boreholes involves the drilling of boreholes into aquifers, to lower the hydrostatic head. Boreholes are drilled through a flanged standpipe and are equipped with gate valves to control the water intersected.

(vi) Grouting, which is a method to check the inflow of water to the mines by embedding rebars and from other neighboring mines. (vii) chemical and isotope analysis, which has been used to fingerprint the various sources of aquifer waters [4].

III. Challenges Of Dewatering And Distribution Problem

Usually minewater may contain abrasive, coal slurry, coal face water, sands and grit. When it enters into the pump unit, it reduces the efficiency of operation. Further, sometimes limited space and unlevelled surface creates problem in installing availability inside mine which leads to use a single stage pump instead multistage pump. But it results low discharge rate. Apart from these, problem of pumping is associated with (i) uncertainty in simulation of mining water inflow due to oversimplifying mining geometry, mine and hydrogeological boundaries, strata section (ii) change in hydraulic conductivity with depth (iii) sudden flood [5] (iv) mixing of mine water directly with underground water and its purification [4] (v) environmental impact of polluted mine water (vi) absence of effective and optimized pipe network to carry out water immediately in flood like situation [6] (vii) cavitation and priming problem in pumps (viii) erosion effects on different components the pump due to suspended solids (ix) incorrect estimation of infiltration and percolation (x) elevated power consumption due to higher density and viscosity, formation of scales etc. For the above said problems different types of pumps have been developed for specify purposes, and different pumping schemes have been employed. In the following sections discussions have been made about the origin of mine pumps towards its developments.

IV. History Of Pumping For Dewatering Mines

Pump has a long history. In this paper major contribution towards the development of the mine pumps is discussed only. Mining is one of the old arts practiced. In the first century an instrument called Egyptian Pumps, invented by Archimedes, used to threw up the water to the mouth of the pit and thus drain the mine with constant pumping. In about 130 B.C. Hero designed a pumping engine that employed heat to displace water in its mechanism air and water were heated in a big vessel and by the expansion of the air the water was displaced however Hero's engine was not find its application in raising water [7]. In 1698, Thomas Savery built a steam pump that could lift water using steam pressure. The device was also introduced in mine drainage system, but its capacity was limited and higher fuel consumption. In 1705 Papin introduced a modified form of the Savery engine by putting a piston between the steam and water pumped [8]. In the same year Newcomen designed an engine which was depended on atmospheric pressure to draw the piston down and by means of the beam to raise the pump rods and piston [9]. Around 1712 Thomas Newcomen's atmospheric steam engine was introduced and by 1725 was in common use in mines. Improvements to this engine were made notably by John Smeaton. In 1760 James Watt advances steam pump design further [10]. More development and modification of pumps has been taken places further. Use of pumps in modern mining industry and its selection are discussed as follows.

V. Selection Of Pumps For Mining Operation

Usually, surface mine developments and underground mine workings below the phreatic level changes the hydraulic gradient, thus affecting the groundwater and surface water flow pattern. As a consequence, flow of water may be induced from the surrounding rock mass towards the mining excavations which may necessarily require pumping large quantities of water and creating extensive and prolonged cone of depression [11]. It is also observed that a significant amount of rainfall enters through various faults, permeable materials and abundant mining parts. Often water retaining beds are encountered during shaft sinking operations. This excess water is pumped, or grouting methods are applied to control it. After sufficient times of mining work a tunnel network forms through that water can percolate. Sometimes underground lake may be formed by extensive anthracite working by pillar and stall methods. It generates large void areas filled with water. Furthermore, natural water tables, sources of drinkable water and surface water flood may cause mine water inundation. This mine water quality is so poor that it usually been controlled in underground by dams. After pumping it to surface huge cost often engaged in chemical treatment process, before passable levels of impurity can be dispatched into the local water bodies. It also reduces live of pumping system, high maintenance costs, breakdown of mining operation and uncontrolled flooding. But, if it is done in systematical matter, it can be a good source of water, where water is scarce in surface. It is found that the dewatering added a fairly constant flow to a receiving river such that the mine water became to be regarded as part of the base flow in the river [12]. Though, it is found that a limited number of mines were developed to provide water for other purposes except few cases where water use and sustainable development in coal mining areas are done simultaneously [13]. In Coal Mining Industry, for maintaining the environment and controlling production machinery pumps are being used. Normally, frictional ignition in coal mines are prevented using chilled water sprays. The chilled water system requires circulating pumping system [14].

Commonly, selection of pump for a pumping network is based on following criteria (i) operating principle (ii) design characteristics (iii) application field of pump (iv) pump drive (v) material of construction. Generally, volumetric displacement pump and kinetic energy pumps are used in mine industry. The volumetric displacement pump is used for relatively low discharge but high pressure of water. Mainly three-throw ram pumps and mono pumps belong to this category which is used to pump mine water containing suspended solids. This type of water damages internal component of pumps like valves, seats and scores stators. In addition, there are many example of interruption of coal production by stators burnt out problem due to air trapping into the pump.

For pumping high discharge and low head water Kinetic energy type pump is used. Generally, instead of single stage centrifugal pump multi stage centrifugal or turbine pump is a common choice for mine water use in shaft bottom schemes and dewatering purposes. The turbine submersible pump also belongs to this family of pumps [1, 14-16]. But the drawback of the turbine pump is, it is not so effective for pumping mine water having suspended solids. Hence settling tanks, baffles and weirs, are used to solve this matter. The disposal of the sludge is very difficult. However iron based ochres and heavy salted waters cause crumble of pumping operation. Along with multistage centrifugal pump like horizontal ring section type and vertical turbine type, electro-submersible type, typical submersible type, simple reciprocating pumps, mono pumps, a positive displacement self priming screw pump are extensively used in the mining industry because of its ability to handle abrasives, coal slurry, contaminated coal face water and many other difficult products [16]. However, the selection of pumps are also governed by ease of installation, local condition, access restriction, risk of local flooding, availability of the skilled maintenance personnel [15].

Generally, the coal preparation plant requires clean water from a borehole, watercourse, and water body or from storage tank for washing purposes. Different mining processes during dewatering mines are shown in Fig 1. The single stage centrifuge is sufficient when water is drawn from the surface. The multi-stage turbine pump works efficiently when water is pumped from a borehole. The centrifugal pump of the kinetic energy family usually requires priming. To handle suspension of coal or dirt in water modifications have been done for pump components, bodies, sealing arrangements, valves and pipes. Since suspended solids results in slurry, therefore, the impellers are modified to be resistant to abrasion, corrosion and shock loading. Many a time rubber coating helps to overcome this problem. Though, after all these modifications, still impellers and volute liners are required to change frequently. These problems leads pumps manufactures to modify and develop new generation pumps for mining operation, which are to be discussed in the following sections.

VI. EFFECT OF MINE WATER QUALITY ON PUMP

First, study of mine water quality needs to be emphasized here especially because of its significant hazardous ramification on mine pumps and pipes. Viscosity of mine water is generally higher than normal water and as the viscosity of the fluid to be pumped increases the capacity and the total head decrease and shaft power increases by keeping rpm constant. It has been observed that higher concentration of slit particle mainly erodes runner and casing of the pump badly which reduces the life of pump and consequently increase its maintenance cost, ultimately induces overall excavation cost to go high. The next problem in the same row is the acidity of mine water. It contains high concentration of dissolved heavy metals and sulphate, and can have pH values as low as 2. But in India majority of mine water falls in the neutral or slightly acidic category [1]. Some of the mines belong to Assam field and in the western coalfields are having the water with pH between 2.5 to 5. The detrimental effect of acid mine water corrode pumps and pipes which is a very critical issue in mining industry. This Acid mine drainage (AMD) becoming toxic as it is being pumped to the surface of disused mines and making contact with air [17]. Moreover due to its acidic character discharge of untreated acid mine waters into natural streams are prohibited as it can affect aquatic flora fauna, aquatic life, and ground water quality. AMD requires proper pumping followed by neutralization of toxins and desalination before its disposal into the natural water systems [18-20].

Therefore, selection of pump is a crucial part here also. The pump should have the ability to carry acid mine water, work smoothly, long life and minimum life cycle cost. Hydra-Cell Positive Displacement Acid pumps [21] has the ability of handling acidic water. Hydra-Cell acid pumps adjusts the pH levels of the process fluid by dosing in acid or caustic as required. One more advantage that is associated with Hydra-Cell pump is that it can handle abrasive material due to its seal-less nature which can process charged and dirty liquids without fine filtration. More of these types of modifications in pumping industry are discussed as follows.

VII. LATEST DEVELOPMENTS IN MINE PUMPS

In most of the cases, the pumps are required to handle muddy, acidic slurry of water, chunks of coal and coal fines, dust, dirt and rocks. Coal fines are extremely abrasive for the internal components of a pump and dramatically shorten the life of a traditional pump when used in such harsh conditions. These days, submersible pump is replaced with a new breed of pumps like BJM KZNR150 Severe Duty Slurry Pump. It features hardened ductile iron volutes cast with extra thick walls where pumped slurry enters the discharge. It is a highly durable, high discharge pump [22]. Another efficient pump is Watson-Marlow Bredel SPX hose pumps, which replaces centrifugal slurry pump and positive displacement pumps to deliver the desired flow rate for the solids of the zinc and lead thickener underflow slurries [23]. Whereas, NSSh Model Pumps are used in mines for maintaining of a normal water level and as a part of dewatering plants [24]. These are ring-section type, horizontal, multistage centrifugal pumps that has high suction capability and single flow impeller arrangement with antifriction bearings. These pumps are designed to handle mine water with aggressive material and liquids having pH value ranges 6.5 to 8.5 at temperature level upto 80°C. Becker Alert Pumpmor manufactures a range of flameproof submersible and slurry pumps, designed especially for the coal-mining industry. These heavy-duty submersible and slurry pumps provide efficient service in arduous environments and having flameproof accreditation. The CKX-U or CTMS models, which are available in vertical or horizontal configurations, can be direct or belt-driven. The vertical model is suitable for wet-sump and dry-pit installations. These pumps are able to handle solids ranging from 60 mm to 228 mm and specific gravity of up to 1.8. Furthermore, high performance Goulds (Morris) large-solids slurry pumps has a flexible drive arrangement including a belt, direct or overhead belt drive. Other options in this range are vortex pump designs and mechanical agitation that ensures highly efficient solids pumping and sump cleaning capacity. These pumps also have an effective method of hydraulic agitation on vertical spindle and submersible pumps [25]. Minova USA Inc. has both electrically and pneumatically driven pumps for mining which ranges from reciprocating pumps (dual operating) to radial piston type with piston membrane technology viz. modular remote dredging pump like CT-PM, pneumatically-driven reciprocating pump like DP 40 injection pump, dual operating reciprocating pump like PHP phenolic resin pump, pneumatically-driven gear pump like SK 90 and electrically-driven pump like WF 100 potassium silicate conveyer pump which have piston membrane. All pumps are having easily replaceable wearing parts, so maintenance friendly [26]. Liquid ring vacuum pump and compressor manufacturer Vac-Cent Services build a rotating positive displacement liquid ring pump, which uses suitable liquid to act as a liquid piston and are powered by an induction motor [27]. These developments in the pump industry help mining engineering to develop efficient pumping network for particular purpose. Following discussions are related to the pumping network i.e. different pumping scheme, history of pipe network, its development and latest software for the calculation of piping networks parameters.

VIII. Pumping Network In Mines For Dewatering

As discussed in the previous sections, it is evident that mine pumps have been changed a lot from its origin and selection of pump is mainly driven by the purpose. Along with selection of pumps, different pumping schemes are also very important issue in mining operation. Pumping schemes have immense effect on developing pumping network. Whereas, a pumping network includes selection

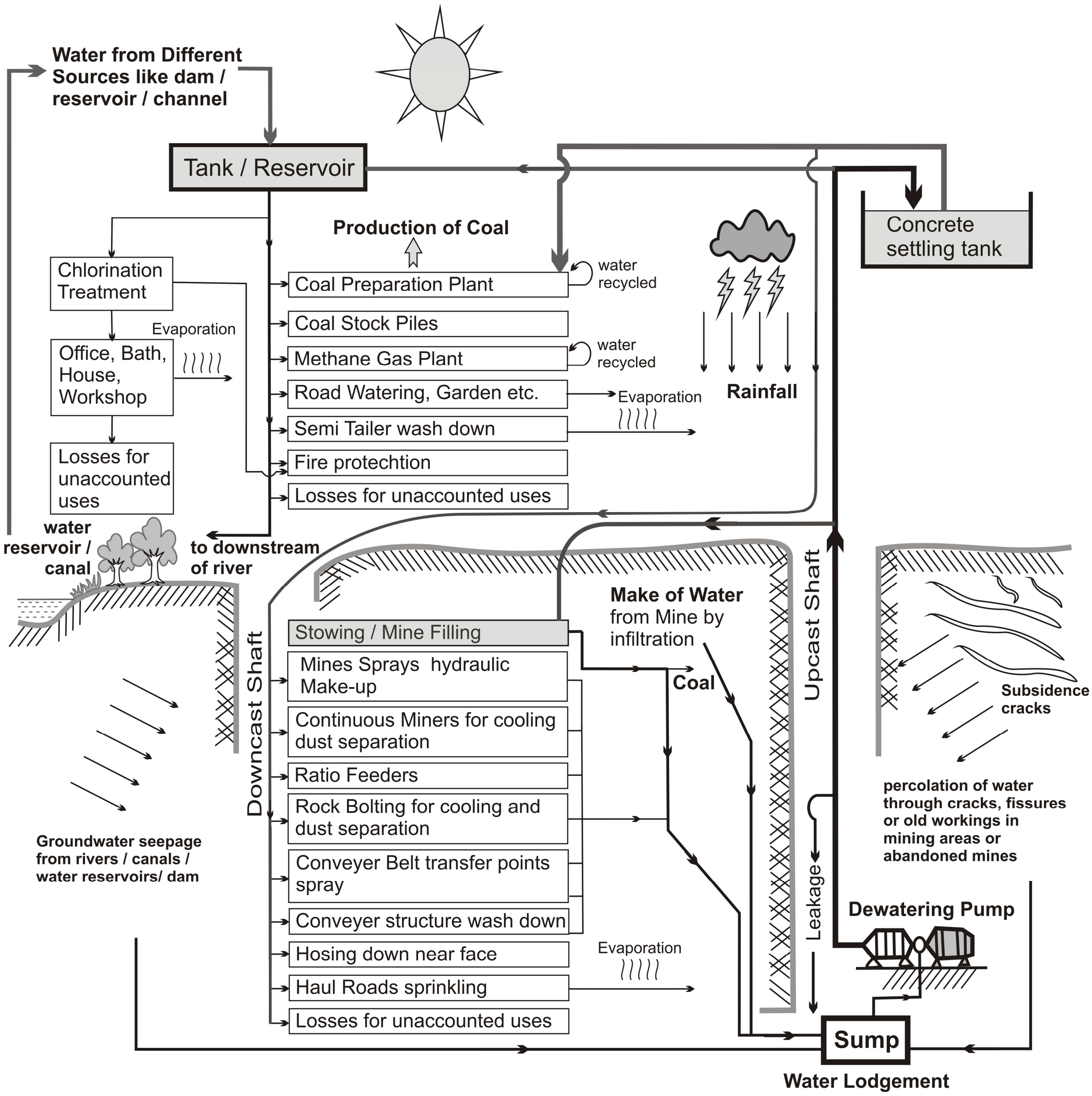

Fig. 1. Different process while dewatering underground mines

of pump and pipe network both. Piping systems or pipe network is like arteries and veins of water supply system. It conveys waste of the system to the treatment plant or to the discharge point. The design of various piping systems, its construction, operation, and maintenance involves knowledge of piping basics, information about materials, fabrication aspects [28].

Piping includes pipe, fittings, flanges, gaskets, bolting, valves, pipe hangers, supports and the pressure controlling components. The use of pipelines has ancient history. The art of design and construction of piping systems and pipelines dates back to the earliest civilizations. For example, around 400 B.C., to transport natural gas Chinese implemented bamboo pipes rolled with waxed cloth. In addition, the Romans used lead pipes to supply water in their conduit system. Around 4000 B.C., Egyptians used clay pipes for drainage purposes. The turning point was observed in 18th century when an important improvement occurred. Low cost metal pipes (viz. cast-iron) were used as drinking water lines, dewatering purpose, in sewers system, and gas pipelines. In the ninetieth century steel pipe was introduced which greatly increased the strength of pipes of all sizes. Thus, long route transport of natural gas, crude oil, and petroleum products became possible. Initially, threaded joint were used to join these pipes together, but this process was unsuccessful for large pipes, moreover they were prone to leakage under high pressure. Twentieth decade of Twentieth century, electric arc welding technology were used to join pipes which provided leak proof, high-pressure sustainable, more large diameter pipeline network. Another major milestone of the same era was invention of large seamless steel pipe. Mainly, major innovations in pipeline engineering were observed after fifth decade of twentieth century which includes introduction of ductile iron pipe, large size concrete pipes for conveying water, and PVC (polyvinyl chloride) pipe for sewers transport. Innovativeness reached its height when engineers used pigs to clean the interior of pipelines. To increase life of pipeline cathodic protection was applied to pipeline in terms of reducing corrosion. To increase productivity batching of different petroleum products were made in a common pipeline. Different complex engineering were performed by bending large pipes in the field, detecting welding flaws using x-rays etc. Generally, Cast iron and steel pipes are used in mines to carry out the dewatering process, however the selection of pipes depend on several factors like hydrostatic pressure induced by flowing fluid, chemical property of water (acidic, basic or neutral), type of fluid (density), head, tensile strength of pipe material, weight of pipe material etc [29].

Few basic principles of fluid mechanics like (i) continuity principle, (ii) the work-energy principle, (iii) the relation between fluid friction and energy dissipation including Darcy-Weisbach or Hazen-Williams equation are the foundation of pipe network analyses [30]. Junction Continuity Equations are those which are developed from the continuity principle and Energy Loop Equations are those which are evolved from the work-energy principle. These equations constitutes a non-redundant system of equations which is related to fundamental relations between the number of pipes, nodes and independent loops that occur in branched and looped pipe networks. In a pipe network system, a supply source is a point where the elevation of the energy line or hydraulic grade line is established; a junction or node is a point where two or more pipes join. Hardy Cross method is recognised as the oldest systematic method for solving pipe network analysis. Hardy Cross adapted this method from method of moment distribution of structural engineering in 1936 [31, 32]. This method is applicable to closed loop systems in solving the problem of steady flow. Before the ready availability of digital computers in the late sixties of twentieth century's, this method was utilised widely because it was well suited for hand computations. It became the basis of most early computer software, after this method Newton–Raphson method come into existence and it has proven to be superior in solving the nonlinear equations [33, 34]. Later, linear theory method also has been evolved and used widely for solving the problem [35]. The linear theory method is another looped network analysis method. The entire network analysis technique is almost like the Newton–Raphson method where the nodal flow continuity equations are linear but the looped head-loss equations are nonlinear. Methods based on the use of linear programming (LP) have been developed for discrete pipe sizes without 'rounding off solutions' constraints. Morgan and Goulter [36] modified the procedure of Kally [37] linked to Hardy-Cross network solver with LP model. The model is designed to optimize both the design of new and modified piping system. To improve the efficiency of computation technique researchers tried to realise the network first by proposing wide variety of methods. One of the most popular methods is the Linear Programming Gradient (LPG) method [38, 39]. Nevertheless, inefficiency of this method compared to other methods was pointed out by Bhave and Sonak [40]. Gessler [41] proposed optimized feasible solutions in pipe network design by linking a network hydraulic simulated model to a filtering subroutine Davidon-Fletcher-Powell method was adopted by Chiplunkar, et al. [42] to design a water distribution network under a single demand loading condition. Later, generalized reduced gradient (GRG) algorithm was adopted by Lansey and Mays [43] for pipe network analysis.. They coupled GRG with a simulated water distribution model to find out optimal sized pipe network, pump stations capacity, and tanks volume. Now a day, networks of more numbers of pipes can be analyzed using different software package also.

Additionally, Taher and Labadie [44] proposed a Geographical Information System (GIS) based advanced water distribution decision support system (DSS) which has user-friendly database supported interface with mapping facility. This DSS, developed into ArcView 3.1 extension, is named as WADSOP - Water Distribution System Optimizer [45]. WADSOP optimizes pipe and pumping station sizing and layout for better cost-effectiveness and reliability. Application of GIS in pipe network analysis provided spatial information as input into the network design model in terms of pipe layout, cost, network routing, its allocation, pressure gradients, demand patterns, and gave output as graphic display. Later, Morley et al. [46] developed an integrated optimization model, GA*net*, which contains genetic algorithm (GA) application, GIS and hydraulic network solver together. Zhang [47] integrated GIS and Computer Aided Rehabilitation on Water Networks (CARE-W) to manage water distribution networks and the rehabilitation planning. Results obtained were displayed in GIS maps, tables, and graphics, which proved that GIS is a competent and effective tool for managing water distribution networks.

More literatures have been found emphasizing reliability issues along with optimization in water distribution system design. Lansey, et al. [48] proposed a chance constrained pipe network model to consider uncertainties in water demands, pressure head, and roughness of pipes. Bao and Mays [49] applied Monte Carlo simulation methods to measure system reliability but this model failed in large-scale system. Chandramouli and Malleswararao [50] developed a fuzzy logic concepts based overall network reliability model. This optimization model combined GA and EPANET software in the MATLAB environment. Similarly, Yannopoulos and Spiliotis [51] proposed a methodology for evaluating water distribution system reliability, which is developed and demonstrated on a simple water distribution network based on the minimum cut-set approach. Here, overall reliability index is proposed based on both the hydraulic and the mechanical reliability with the help of fuzzy algorithm. Di Nardo et al. [52] worked on water supply network which is exposed to many diverse potential sources of intentional contamination or malicious attacks when a pump system is utilized to overcome the pressure gradient of network pipes which is easily available on the market. Also, the network vulnerability has been analyzed by computing the lethal dose of cyanide ingested by users and the total length of the contaminated water system.

A very few literature regarding the piping network modeling in mines has been found. Hua et al. [53] has proposed a holistic approach on ventilation networks in coal mines. Since it controls fluid flows, authors also admitted that this approach is applicable to water distribution networks in mines. Chen and Dehai [54] developed a model to design and realization of ArcGIS Engine-based 3D pipeline networks underground. Zhe-xiang and De-sheng [55] discussed about the development of pipeline and hydraulic transport of mine filling. The research and application on transport by gravity, effect of slurry at low density on mining, grain-size gradation of pumpable filling, life of transport equipment and reliability of backfill system with pump transport, and pipeline squeezed-transport also have been discussed. The problems and trend of development on mine filling pipeline transport are also discussed in this paper. For a mine water system network, Gunson et al. [56] demonstrated a method to determine the lowest energy option, which used LP to compare various possible combinations of water supply to mine and optimized it.

IX. CONCLUSIONS

A suitable mine dewatering system should have pumping system which can cope with the required seepage water under most adverse conditions; it must be reliable with minimum maintenance and cost effective. Here, in this paper, during review of literature, detailed discussion about selection of pump, types of pipes, pumping schemes have been made which are essential for designing a good mine pumping network. Over the years, extensive modification has been observed in pump industry to handle AMD, slurry transport by adopting hard coated pump impeller, sophisticated pump membrane technology, and so on. In literatures, espousal of different pumping scheme also has been observed which are used in Indian coal mining industry. Moreover, discussion about piping network has been made. Advancement of piping network from its beginning to the latest optimization technique, integration of piping network with GIS environment has been observed in several literatures for the betterment of the understanding of the end users. Development of software for handling complex pipe networking system having large number of pipes has been noticed. Unfortunately, these developments have been found in the water distribution sectors only. Very few literature reviews has been found regarding pumping network in mining industry. After reviewing all these literatures, authors feel that mines pumping network is taken for granted and ignored until some malfunction results in a break to normal workings. As a result, this field is seems to be quite neglected from research or academic point of view. Henceforth, research in mining industry should focus on improvement of the pumping network also in future. Authors feel that piping network coupled with GIS has a very good prospect in mining industry. For, pumping network, 3D network analysis could be done with the help of latest sophisticated software like WATERGEMS. Statistical analysis regarding estimation of water inflow towards mines can be done with the help of latest technologies which will be supported by the above said software. Optimization study could be performed for the minimum cost of dewatering mines. Reliability study can be done also on mine dewatering process in the light of water distribution network models. Hope, the research directions discussed here will reduce the gap between the academic and industry, thus, the optimized and reliable pumping network models for dewatering mines will have widespread acceptability among the mining engineers.

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