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Improving the Efficiency and Performance of Underground Water Purification Plant in the Gold Mine

P. B. Sob[a], **M Pita**[b]

[a]*Department of Industrial Engineering and Operation Management & Mechanical Engineering, Faculty of Engineering and Technology, Vaal University of Technology, Vanderbijlpark 1900, Private Bag X021, South Africa.*

[b]*Department of Mechanical Engineering, Faculty of Engineering and Technology, University of South Africa*

Abstract

Most of the gold mine refrigeration system fails when the operating temperature at inlet of the underground water supply is 40oC when the system efficiency is 35%. This often leads to mechanical and industrial break down during operation resulting to shot down in operational activities. The system efficiency and pump efficiency is very low resulting to cavitation which leads to industrial failure and mechanical failures. In the current paper, the design of a gold mine was optimized by modelling the major external and internal parameters that affects the system efficiency and performance of an underground water purification in a gold mine. The tool of computational fluid mechanics and random mechanics was used to model the change in temperature of the system which affects performance and system efficiency during operation. The following fact were revealed after theoretical modelling and simulation. Simulated heat exchanger using the CFD revealed that the pressure and length of the heat exchanger were observed to be directly proportional to the mass flow rate, thickness of the tubes, the material type, and inlet and outlet temperatures. The outlet temperature of the buffels water was 15.8℃ simulation results revealed 18.6℃ which was still acceptable and will not affected the cooling duty of 4MW of the evaporator. The evaporator performance was projected to be restored back to its operating designed limits and by that so, the refrigeration plant was optimized after detecting the optimal operating temperature from empirical modelling.

Keywords: efficiency, performance, temperature, evaporator, and flow.

I. INTRODUCTION

Most heavy refineries plants, steel industries and gold producing mines are built with a proper cooling system for optimal performance during operation [1]. These systems are either air cooling or liquid cooling however most bulk system used liquid cooling for efficient performance during operation [1-4]. The liquid cooling systems control temperatures and pressures by transferring heat form hot process fluids into the cooling water, which carries the heat away. This normally used a continuous recirculation system as hot water is less dense than cool water and there is a continuous recirculation of water in the entire system during operation [1-4]. As this happens, the cooling water heats up and must be either cooled before it can be used again or replaced with fresh water [1-2].

In the mine industries, underground heat exchanger work in two stages are normally used but the performance and efficiency are not stable and efficient [3-4]. The basic science of operation is that heat is transferred when these two processes are in direct contact with a thin wall [5-7]. This is a conduction process in which heat flows from the hotter body to the cooler body when two bodies are brought together at different temperature. Heat Exchangers are grouped into two section which is the direct and indirect heat exchangers. The direct heat exchangers operate within direct contact between the two fluids. The indirect heat exchangers uses a heat transfer medium. Pre cooling towers and cooling towers are an example of direct heat exchangers, while shell and tube or plate heat exchangers are good example of indirect heat exchangers. In the refrigeration plants there are normally two main types of indirect heat exchangers being used which are the shell and tube heat exchanger and the plate type heat exchanger [3-7].

In underground gold mine system, a shell and tube type design is most commonly used heat exchangers. This heat exchanger consists of a bundle of tubes inside a shell. Cooling fluids passed through the tubes, and the other fluid flows inside the shell and around the tubes. Heat is normally transferred through the walls of the tubes during this process [4]. The tubes are often finned to, increasing the surface area allowing great heat transfer to take place and thus increasing the duty. These heat exchangers can be made in a number of passes, with one pass being when the fluid flows into the tubes at one end, through the tubes and out at the other end. Multiple pass shell and tube heat exchangers can be made by redirecting the fluid back through the tubes again, this in effect doubles the exposure time of the fluid, making heat transfer more effective. There are a number of considerations that need to be taken into account when designing a shell and tube heat exchanger such as: (1) Tube diameters, using smaller tube diameters is cheaper, however this makes cleaning more difficult. (2) Length, the important characteristic of any heat exchanger is the surface area, this can be increased by either adding more tubes or by increasing the length of the tubes. In general increasing the length of the tubes is more cost effective. (3) Materials, the tubes are susceptible to corrosion and the build-up of scale, thus the material that they are made out of must be carefully considered [3-6]. In most refrigeration systems cupronickel (90% Copper, 10% Nickel) or stainless steel are used. (4) Maintenance, dirty tubes (build-up of scale) can drastically reduce the performance [2-6]. The tubes must be cleaned on a regular basis, there are a number of ways to do this such as reverse flushing with brush inserts or ultra-sonic vibration [2-6]. The most efficient heat exchanger is the plate heat exchanger.

Plate heat exchangers are a very effective alternative to the shell and tube type heat exchangers. The plate heat exchanger is commonly used on the Ammonia plants. This heat exchanger is more effective than other heat exchanger and has a number of advantages including that the heat exchanger is more efficient as it has a much higher surface area of contact for the fluids than that of a similarly sized [2-5]. The design can be improve by either increasing or decreasing the capacity of the heat exchanger either by adding or removing plates [3-5]. The maintenance process is not complicated as it is easy and straightforward. The possibility of Freezing during operation can occur without damaging the heat exchanger in the system [2-5]. However the system suffers from major deficiency such as relatively large pressure drop across the heat exchanger during operation due to the small channels and complicated path [2-6]. The heat exchanger in the system cannot be used for evaporative or condensation of heat transfer. The system requires a surge tank for heat transfer occurring with a change of state during operation [2-5]. The maximum pressure of the heat exchanger is limited by the sealing capabilities of the seal. Centrifugal refrigeration machines for water chilling duty use horizontal shell and tube exchangers. The water passes through the tubes in both the condenser and the evaporator, and the refrigerant is contained within the shell [3-6]. This arrangement permits mechanical cleaning of the inside of the tube when the head of the exchanger is removed. This is desirable because of the potential fouling of the tube inner surface by dirt or salts paper a method is proposed and a suitable heat exchanger was design based on simulation of the relevant parameters proposed.

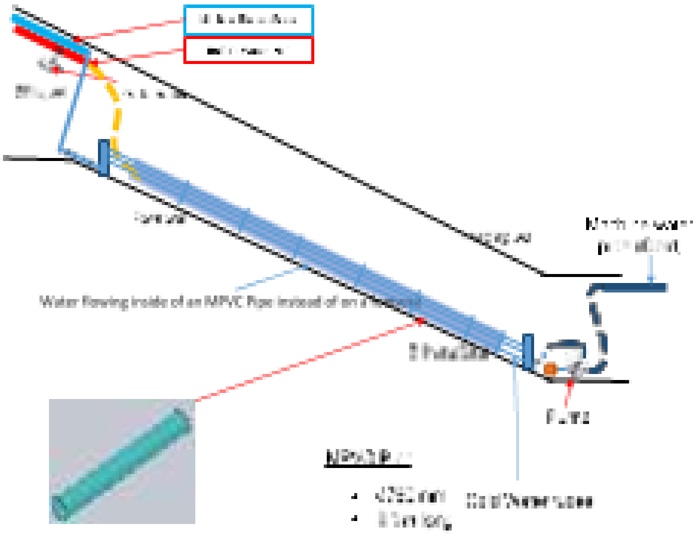


Figure 1. Proposed design of the heat exchanger in the current study

The number of tubes was to be estimated for efficient and optimal operation of the system. The theoretical relationship between the parameters of the flow rate (mt) as a function of the ρ density of the fluid (t), the velocity of the fluid (ut), cross- sectional flow area of the tube (Ac), and the number of tubes (Nt) is was modelled theoretically using

$$m\ t = \rho tut\ AcNt \qquad [1]$$

From equation (1) the number of tubes is computed for optimal performance using standard principles given as

$$N_t = \frac{4m_t}{\rho_t u_t A_c} \qquad [2]$$

After computing the flow rate during the system operation and number of tubes recommended for optimal performance, it was important to determine the kind of flow that is taking place if it is laminar of turbulent flow inside the pipes. The Reynolds Number for the system was computed using contained in the water. This has decreased the system performance and for stable and efficient operation this major deficiency must be address [2-6]. In this paper the efficiency and stability of the underground water purification system is improved by modelling the capacity of the heat exchanger for optimal performance during operation.

$$Re_t = \frac{\rho_t u_t d_t}{u_t} \qquad [3]$$

The design (thermal) process of the heat shell-tube exchangers was directed to calculate an adequate surface area to handle the thermal duty for the given specify parameters whereas the hydraulic analysis determined the pressure drop of the water flowing in the system. The pumping power work input necessary to maintain the flow was had to be considered. In this where t is the viscosity of the tube-side fluid, ut is fluid velocity inside the tubes, and ρt is the density of fluid in the tubes. It was also important to determine the tube side Nusset number during operation. Nusselt number is a function of Reynolds number (Re) and Prandtl number (Pr). The derived model developed according to the type of flow is given as

$$Nu_t = \frac{(f/2)\mathrm{Re}_t \mathrm{Pr}_t}{1.07 + 12.7(f/2)^{1/2}(\mathrm{Pr}_t^{2/3} - 1)} \qquad [4]$$

Where f = (1.58 ln Ret −3.28)^2 for standard modelling and simulation process. The heat transfer coefficient is given as $h\ t = \mu t\ kt/$d1 and the shell diameter. the projected area of the tube layout expressed as area corresponding to Ds is the shell inside diameter CTP is the tube count calculation. It accounts for the incomplete coverage of the shell diameter by the tubes, it is due to necessary clearances between the shell and the outer tube circle and tube omissions due to tube pass lanes for multitude pass designs. Values of CTP for different tube passes are given in table 1

one-tube pass → CTP= 0.93 two-tube pass → CTP = 0.90

three-tube pass → CTP = 0.85

PT is the tube pitch and CL is the tube layout constant. For 90° and 45° → CL = 1.0

For 30° and 60° → CL= 0.87

$$\frac{1}{U_c} = \frac{1}{h_o} + \frac{1}{h_i}\frac{d_o}{d_i} + \frac{r_o \ln(r_o/r_i)}{k} \quad [5]$$

It was important to do the thermal analysis of the wall and tubes during operation. The overall heat transfer of the heat exchanger is computed using

$$= (m\ cp)h\ (Th\ 1 - Th\ 2\ ) + T \quad [6]$$

Equation 1 to equation 6 give the theoretical models of the number of tubes and operating temperature during the system operation. The equation are simulated using computational fluid dynamics (CFD) heat exchanger software and obtained results are discussed. During water purification process when raw water at a pH of 6,8 is treated with milk of lime, which is pumped underground from a slaker situated in the Reduction Plant shown in Fig.2 (a), the pH value is increased to approximately 8,5 to reduce corrosion caused by the chlorides in the water and to increase flocculation as shown in Fig.2 (b). Since the flocculent used forms a gelatinous substance in water that is difficult to dissolve, batches of 0,9 kg of flocculent powder are mixed by air agitation with 182 litres of water in a tank. Small notched launders then distribute the mixed flocculent evenly across the raw- water stream at an average rate of 0,57 kg per mega litre of water. Although the stilling box terminates 1830 mm below the new flow level, the water velocity continues downwards, eventually fanning upwards towards the peripheral overflow lip. Particles settle out against a rising current induced by the overflowing water; hence, the action within the settler is that of counter current settling. This was verified by samples taken from various points in a working settler using a long pipe with a stoppered end. When the pipe was in the desired position for a sample to be taken, the stopper was pushed out with a stiff piece of wire attached to the stopper through the bore of the pipe, thus allowing water to enter the pipe. The depth and position of the sample were recorded, the stopper was pulled back, and the sample was removed for analysis.

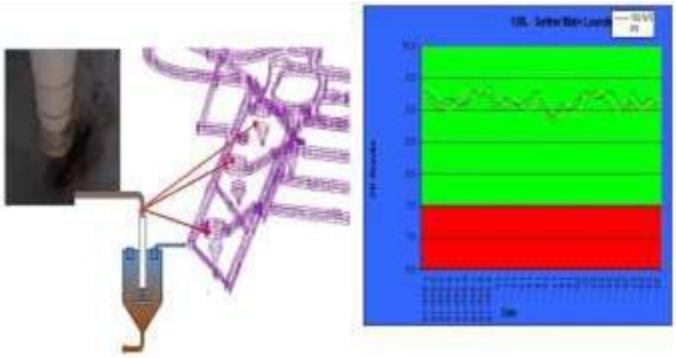
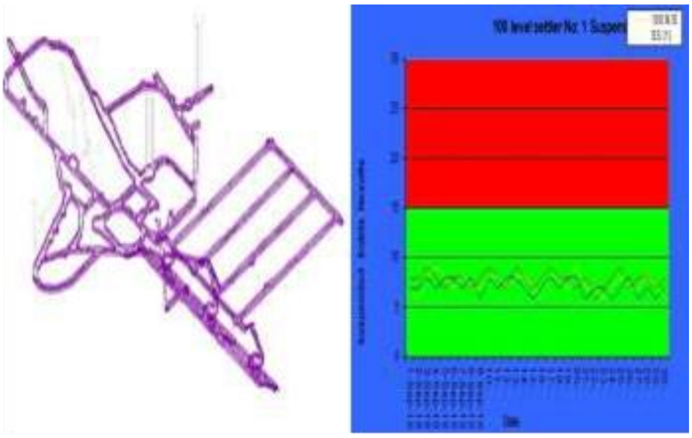


Figure 2 (a) the layout and structured of a settler during operation **(b)** PH levels and months

ho is the shell-side heat transfer coefficient hi is the tube-side heat transfer coefficient ro is the tube outer radius, ri is the tube inner radius, and k is the thermal conductivity of the tube material.

The pH level is also improved and it ranged between the 9 & 9.5 as shown in Fig. 2 (b). That reduced the alkaline content of water, therefore scaling and slit built up will take place at a very low rate. The simulated heat exchanger using the CFD, the pressure and length of the heat exchanger were observed to be directly proportional with keeping the mass flow rate, thickness of the tubes, the material type, inlet and required outlet temperatures the same. The outlet temperature of the buffels water was 15.8℃ simulation were as the calculation reflected 18.6℃ which was still acceptable and will not affected the cooling duty of 4MW of the evaporator. The evaporator performance was projected to be restored back to its operating designed limits and by that so, the refrigeration plant was optimized. The relationship between the design of settler and suspended particles are also analyzed.



(a) (b)

Figure 3 (a) Design of Settlers used to purify water (b) suspended particles and months

Water can be seen after having passed the flocculent but before entering the settler and after having left the settler. Looking closely at the water before it enters the settler, it was reported that flocculent has started to work as the mud particles have already begun to group together, giving a milky appearance. The water quality at the exit of the settler needs to be tested each shift to ensure that the water is within specification. The maximum tolerance for the particles in the water is 25ppm and the minimum pH level is 8.3. In order to maintain the correct pH levels, lime is added in the launders before the flocculent gel blocks. There are three different types of flocculent that are available depending on the conditions that are present at the mine; anionic, cationic and a combination of the two. The different flocculants are to accommodate for the differently charged particles which are present in the water, which will vary between locations. It was observed that the suspended solids in the settles ranges between 5 and 10 taken measured in different times of the day such as day, afternoon night shift as shown in Fig. 3 (b). it was important to discussed how the evaporator performance was projected to be restored back to its operating designed limits and by that so, the refrigeration plant was optimized during operation.

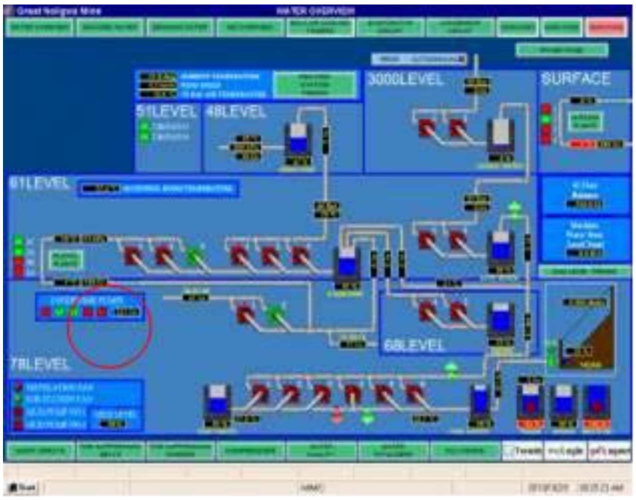


Figure 4: SCADA System showing the different operating level during optimization process.

It is observed from the SCADA system that the inlet temperature going into 61 level refrigeration plant evaporator is 19 ℃. Through obtaining the results and simulation, evaporator performance was projected to be restored back to its operating designed limits and by that so, the refrigeration plant was optimized for efficient performance. There are other operating levels such as shown in Fig.4. this operating levels are design with fans that are used to dissipate the energy stored in the system such that the operating temperature can be stabilize for optimal operation. Therefore it is important to study the effect on temperature during optimal performance.

Figure 5: SCADA System showing the system fluctuation during heat exchanging process

The temperatures of read on the SCADA system fluctuates in the heat exchanger due to the fact that there was a rapid change in the flow rate, and the inlet temperature into the heat exchanger would increase up to 53℃. There is clear evidence or random variation of temperature during operating hours.

3. Conclusion and Recommendation

The current study was aimed at improving the efficiency and performance of an underground water purification system in a gold mine. To achieve this research objectives the efficiency and stability of the underground water purification system is improved by modelling the capacity of the heat exchanger for optimal performance during operation. The following facts were theoretically revealed and validate. It was shown that when raw water at a pH of 6,8 is treated with milk of lime, which is pumped underground from a slaker situated in the Reduction Plant. It was also shown that when the pipe was in the desired position for a sample to be taken, the stopper was pushed out with a stiff piece of wire attached to the stopper through the bore of the pipe, thus allowing water to enter the pipe. It was also revealed that the pH level is also improved and it ranged between the 9 & 9.5 as shown when the system design was optimized for efficient operation. It was also revealed that the outlet temperature of the buffels water was 15.8 ℃ simulation were as the calculation reflected 18.6 ℃ which was still acceptable and will not affected the cooling duty of 4MW of the evaporator during operation. It was finally revealed that the evaporator performance was projected to be restored back to its operating designed limits with optimal performance during operation.

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