THE OPTIMISATION OF WATER PURIFICATION PLANT OPERATIONS AT DARNALL

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Abstract

In June and July 1989, the Darnall Water Purification Plant underwent an optimisation study. Problem areas were identified and solutions found and implemented using a combination of simple rectification steps and innovative technology. The corrosive nature of the purified water was altered by effecting a Stability Index correction, while unsatisfactory elements of the plant control philosophy were addressed. In particular, flocculant dosing control was achieved by means of an on-line Streaming Current detector or Zeta Potentiometer, a first among South African sugar industry water plants. Results to date indicate considerable savings on the plant flocculant budget.

Introduction

The Darnall water filtration plant was partially automated in 1988, and since then has functioned reasonably well, with no particular problems arising. In mid-1989, however, facts came to light that focused attention on this plant and its operation, and it was decided to embark on a plant optimisation study.

Three major concerns were unearthed:

* Unsatisfactory control of the raw water inflow
* The aggressive nature of the purified water
* Unsatisfactory control of flocculant dosing.

The scope of the study was thus defined as the solution of these three problems without compromising filtered water quality or production costs.

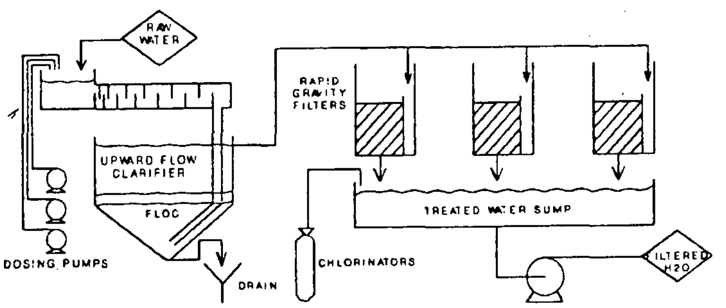

FIGURE 1 Darnall water filtration plant

Plant Layout

Figure 1 is a schematic representation of the plant layout. Flocculant is added to the raw water in an inflow well at the beginning of a mixing channel. The channel consists of an open concrete gutter containing baffles at increasing intervals, and feeds an upward-flow clarifier. The clarifier operates on the principle of a suspended floc blanket through which the water rises. Overflow from the clarifier enters three collection launders which empty into three rapid gravity sand filters. These in turn empty into an underfloor sump where the filtered water is chlorinated before being pumped to the mill and village reticulation systems. Clarifier, filter and sump levels are controlled automatically, as is filtered water pump pressure.

Investigation

Figure 2 is a diagram of the control system that existed in the pre-filtration section of the plant prior to the optimisation study. The following problems existed with this system.

Inflow control

Raw water supply to the plant was controlled via a 100 mm control valve to maintain a constant level in the clarifier. Problems were encountered with this system due to the fact that predominantly on/off type control occurred. This resulted in water surging into the clarifier, consequent disturbance of the suspended floc blanket, and therefore carryover into the filters. Under normal operating conditions the valve was oversized for its duty, and in periods of low demand, particularly at night, the problem was exacerbated.

Attempts to correct this problem by tuning the control parameters were unsuccessful. The fluctuating water demand and the fact that the control valve never opened more than 30% under normal conditions, made it impossible to tune out the valve cycling.

Corrosive water

The perennial problems of reticulation system pipe corrosion and the regular appearance of "red water" (water carrying corrosion products), particularly in the hot water systems, have long been accepted as the norm. However, the problem was highlighted by the costly replacement of a filtered water pipe in the mill due to corrosion holes in the 4 mm wall after only a year's service.

Protection of the entire reticulation system against corrosion by means of a potable water passivator was investigated. Costs were prohibitive, as quotes were in excess of R30 000 per annum.

The Ryznar[1] Stability Index of the water was determined as a measure of its corrosivity. Appendix 1 contains further information on this index. Darnall filtered water registered 11,5 on this scale, which indicates extremely severe corrosive tendencies at all temperatures.

Flocculant dosing

Raw water in the inflow well was dosed with two prediluted polyelectrolytic liquid flocculants. Control of dosing rates was entirely manual. The operator adjusted valves on the dosing lines on the basis of his experience, the appearance of the water and an occasional set of laboratory jar tests. Control was therefore imprecise and lent itself to overdosing, as the operator would always err well on the "safe" side to ensure clear water.

Raw water turbidity at Darnall fluctuates dramatically, with seasonal changes and rainfall-induced step-changes confounding attempts at manual control. In addition, no attempt was made by the operators to cater for fluctuations in the raw water inflow.

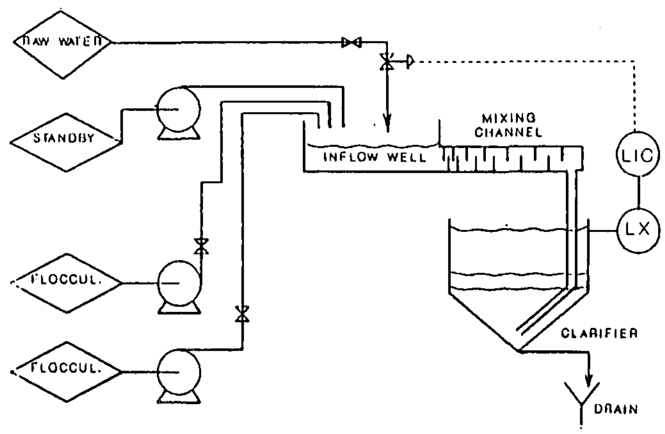

FIGURE 2 Pre-filtration system control: pre-optimisation

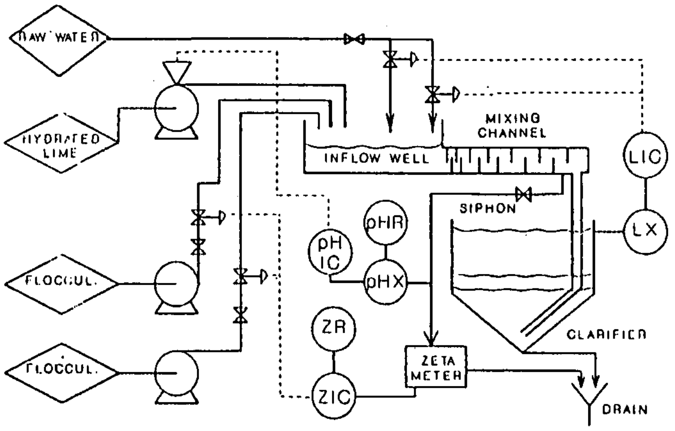

FIGURE 3 Pre-filtration system control: post-optimisation

Action

Inflow control

The raw water inflow was split to cater for the extremes in flow. The 100 mm valve was replaced by 80 mm and 40 mm control valves in parallel (Figure 3). These operate under split-range control, where a 0 to 60 kPa output from the controller acts on the 40 mm valve, and a 60 to 100 kPa output acts on the 80 mm valve. This means that the small valve will open first, followed by the large one as demand increases. The system therefore retains its capacity to cope with peak demands, while having the facility for very fine control actions via the small valve during low demand periods, particularly at night.

Corrosive water

For a corrosive system, an improved (lowered) Ryznar Stability Index is achieved by increasing the calcium hardness, total alkalinity and pH. It was decided therefore that the simplest rectification method would be the addition of lime. It was accepted that this would also have a very small adverse effect on the index by increasing the TDS.

Liming began on 11 July 1989 employing the existing standby centrifugal dosing pump. White hydrated lime in powder form was slurried at less than 1% by mass and added at the raw water inflow well. Settling in the dosing line was prevented by bleeding lime off a closed recirculation system. The operator regulated the manual lime bleed-off valve, aiming at a filtered water pH of 7,8 (natural pH is 6,5 to 7,0). Stability Index is checked routinely by determining Ca hardness, total alkalinity, TDS and pH and calculating the index from these data (neglecting the influence of the velocity term).

The liming and pH system is in the process of being automated. The completed system is represented in Figure 3.

Flocculant dosing

The effectiveness of and requirement for flocculant dosing may be accurately measured using the concept of Zeta potential. A detailed discussion on this topic is contained in Appendix 2. The point at which a treated water's turbidity reaches a minimum corresponds to a zero residual ion charge, or Zeta potential (Figure 4). This in turn would correspond to the optimum flocculant dosage for that water. An on-line measurement of Zeta potential therefore provides a direct indication of whether too little flocculant (-ve charge) or too much (+ve charge) is being used.

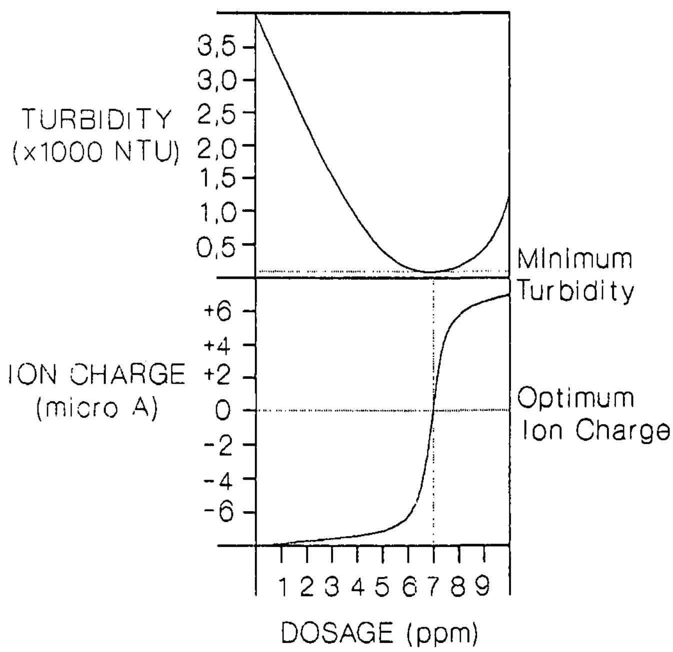

FIGURE 4 Typical turbidity/ion charge relationship

An on-line Zeta potentiometer or "Streaming Current Detector" was obtained locally and installed for a plant trial on 14 July 1989. The trial lasted 23 days, during which the instrument was left to record the ion charge trace during actual plant operation. Operators were instructed to control dosing in the normal manner rather than by reference to the instrument. This provided an accurate picture of current dosing practice.

On analysing the recorded ion charge traces, the correct charge band (i.e. correct dosing rate) was observed for only 11% of the trial period. The plant was underdosed for 9% of the time while overdosing occurred for 80% of the time tested! Of the latter, 22% of the time saw dosing at more than twice the optimum rate. In addition, results showed the expected inadequate turndown of dosing at night and highlighted the cycling problem with the raw water inflow valve. Frequent fluctuations, poor reaction times and excessive "overshoot" indicated the inadequacy of manual control. Finally, the recorded ion charge trace was always reasonably smooth and did not exhibit any oversensitivity or noise.

On the basis of the trial results, it was decided to automate the flocculant dosing system. A Streaming Current meter was purchased and installed at the plant in mid-September of 1989. A sample of raw water is drawn through the meter via a siphon from the end of the raw water-flocculant mixing channel. The meter provides a 4 to 20 mA input signal to a controller which then regulates flocculant dosage by means of two half-inch control valves (Figure 3). The ion charge trace is recorded for operator information and historical purposes, as is the controller output signal so that inordinately high or low dosing rates may be noticed and corrected.

Results

Inflow control

Raw water inflow control has been effectively smoothed, with no further incidences of on/off valve action having been reported. The installation has also coped with abnormally high demands (e.g. when providing boiler makeup water).

Corrosive water

Liming has dropped the Stability Index of the filtered water to an average of 8,3, which, although still in the corrosive range, poses a greatly reduced threat to the cold water mains. Since the commencement of liming, no further cases of red water have been observed or reported. It appears that further improvement in the index will only be made by expensive chemical treatment.

Flocculant dosing

In commissioning the automatic dosing system, problems were experienced with the excessive time lag between a control action and the detection of its effect. This delay could not be reduced without reducing the essential mixing and reaction time required after flocculant addition. The problem was successfully "tuned out" and straight line control is now being approached.

Fluctuations in demand and raw water turbidity have been handled extremely well. The five months since commissioning have seen heavy rainfall as well as very dry periods, with consequent dramatic swings in raw water turbidity. On every occasion, the Streaming Current meter has detected the change, frequently before it became visible to the operator, and adjusted the dosage to ensure clear water. As a result, plant performance has been optimum, with water clarity consistently excellent. Staff have also been freed from time-consuming and subjective jar tests.

Table 1 is a summary of flocculant usage per megalitre of water processed for the five months since commissioning, compared with the same period in 1988/89. Savings in October, December and February were considerable at an average for the three months of 35,5%. In November 1989 Darnall experienced the second highest monthly rainfall in the last 60 years (452 mm), with an associated high raw water turbidity throughout the month. When this is compared with the November 1988 rainfall figure of 98 mm, the negligible change in flocculant usage becomes remarkable. January saw a much smaller saving achieved because the Streaming Current meter was off line for approximately two weeks for instrumentation relocations and alterations.

Table 1
Flocculant usage comparison

Month	Flocculant usage (ppm)		% Saving
	1988/89	1989/90	
Oct	25,7	17,8	30,6
Nov	22,2	22,3	−0,4
Dec	28,5	22,6	20,7
Jan	20,4	19,4	4,9
Feb	22,5	10,1	55,1

The Streaming Current-controlled dosing system allows precise tailoring of the clarifier overflow to suit requirements by simply adjusting the Zeta potential setpoint. This allows regulation of the load on the filters and the consequent filtered water clarity, and true plant optimisation may take place when these parameters are balanced with flocculant costs. In addition, a comprehensive record is being built up of daily dosing profiles through the recording of the controller output to the valves.

The Streaming Current meter is robust and will run accurately for long periods without cleaning. The instrument was run without cleaning intentionally during the plant trial, allowing the sample chamber to become severely fouled with floc, with no ill effects.

The instrument can also be used to assess objectively the relative efficacy of commercially available flocculants, allowing selection on an "available charge per Rand" basis.

Costing

Correction of the raw water inflow control problem was done at negligible cost, as the 40 mm valve and both actuators were salvaged from other applications.

Liming was achieved at an initial installation cost of R2 000, with a predicted extra R7 000 for the installation of automatic pH control. White hydrated lime costs approximately R2 000 per annum. Returns via reduction of the corrosion rate throughout the reticulation system are difficult to quantify, but it is anticipated that corrosion coupon results will show substantial savings.

Automation of flocculant dosing using the Streaming Current meter cost R24 000 in total, including the controller, recorder and ancillaries. Based on the plant trial results in conjunction with figures from the last five months, it is projected that at least 30% of the annual potable water flocculant budget will be saved. This represents R30 000 per annum, which means a payback time of less than 10 months.

Conclusions

The optimisation of the Darnall water filtration plant has been completed but for a few minor features. Attention must be paid to further reduction of the filtered water corrosivity, with closer monitoring of actual corrosion rates. The acquisition of automatic variable speed dosing pumps and facilities to pump undiluted flocculant from bulk supply storage tanks will further hone operation and reduce costs. Steps taken thus far, however, have reaped, and will continue to reap rewards in the form of improved plant performance, consistently clear water and considerable financial savings.

Acknowledgements

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REFERENCES

1. Ryznar, JW (1944). A new index for determining amount of calcium carbonate scale formed by a water. *Journal of the American Water Works Association* 36, 472.

APPENDIX 1

Ryznar Stability Index

The Ryznar Stability Index is a measure of the corrosive or scaling tendencies of water. It comprises a scale from 0 to 13, with 0 being extremely scaling and 13 being extremely corrosive. At approximately 6 on the scale, water neither scales nor corrodes metal surfaces. The Index is determined as follows:

$$RSI = 2\,pH_S - pH$$

where pH = water sample pH
pH_S = Langelier Saturation pH

and

$$pH_S = \log \frac{K_S}{K_2} - \log(Ca^{++}) - \log(Alk) + 9{,}30 + \frac{2{,}5.u^{0{,}5}}{6{,}5 + 5{,}3.u^{0{,}5}}$$

where (Ca^{++}) = Calcium ion concentration (ppm)
(Alk) = Total alkalinity (ppm)
u = Average water velocity (m/s)
K_S = Activity product of $CaCO_3$
K_2 = Second dissociation constant of H_2CO_3

K_S and K_2 are both functions of temperature and total dissolved solids. In general, an increase in either TDS or temperature will increase the value of the K_S/K_2 term and therefore increase the saturation pH, and consequently also the RSI.

APPENDIX 2

Zeta Potential

Suspended clay or silt particles remain in suspension in water due to their surface charge. With a salt, e.g. sodium chloride, solution in water occurs when the sodium and chloride ions are separated in the water phase by being surrounded by water molecules. In the case of larger pseudo-salts, e.g. aluminosilicates (clays), the positively charged counter ions (e.g. sodium) are only partly separated from the very large negatively charged clay cage structures. Some of the positive ions remain quite closely bound to the clay particle in what is known as the Stern layer. The rest are mobile and in the water phase itself, leaving each of the cage structures with an effective negative charge. This difference between the total negative charge on the clay particle (the Nernst potential) and the positive charge contained in the Stern layer is called the Zeta potential.

Most naturally occurring substances in suspension develop this residual negative charge, and it is this charge which causes particles to repel one another, preventing agglomeration. If the charge were absent, particles could approach one another closely enough for van der Waal's forces to cause agglomeration. Particles so formed would be too large to be supported in Brownian motion by the movement of the water molecules and would settle. Water flocculants therefore work by neutralising these residual surface charges and then providing bridges which bond the particles together, allowing rapid settling.

Zeta Potential is traditionally determined in the laboratory by means of a cell consisting of two flat plates with an electrode at each end. Particles in the water sample between the plates are observed using a microscope, and may be seen to drift towards one of the electrodes when an electrical potential is applied. The Zeta potential may be calculated from the speed of drift, and the direction of drift indicates the predominance of either cations or anions.

An on-line Zeta Potentiometer is to a laboratory Zeta potential cell what a generator is to a motor. It operates by forcing a flow of water through a capillary between two electrodes, which induces a current if particles in the water are charged. The magnitude of the current is proportional to the total amount of residual charge on the particles. The instrument is calibrated to give a negative reading when the particles are negatively charged, and a positive reading if positively charged.