1 Introduction

The overall aim of the Reffiplant project is to improve efficiency of resources (materials, water, energy) in integrated steelmaking plants both by minimising them at source and by finding integrated solutions for recycling, reuse, and treatment of waste water. In this regard, PIL (Process Integration Limited) studied water systems at Tata Steel plant and identified several process integration (PI) based solutions which can be replicated by other steel plants.

Details of these PI based solutions can be found in the Reffiplant final report. However, the idea behind this document is to reflect upon our experience and develop guidelines illustrating the correct way to formulate such problems, and the subsequent steps to be followed and the analysis to be made in order to reach the optimal solution. It has taken 3 years of investigation and research work to apply process integration methodology on steel plants and it is aimed that by means of this document, tools developed and other divulgation materials from this project, engineers from other steel plants will be able to replicate such case studies in their respective steel plants.

This document starts with generic work process and generic guidelines which can be applied for the development of any case study in steel plant water systems. This is followed by case study specific guidelines on applicability and nature of solutions that can be achieved from such case studies.

2 General Work Process Followed by PIL

As far as the analysis of the case studies related to the Tata Steel water network is concerned, PIL followed a three step work process in order to identify the improvement opportunities and carry out further optimisation work. The details of the work process are illustrated in Figure 1.

The work process highlights the importance of engaging with operators and technical staff directly involved in day-to-day operations of the plant. One of the difficulty faced while conducting water studies is the lack of available data. In general water systems are scarcely monitored and it takes several weeks to get reliable spot measurements. Thus asking for large amount of data without engaging operators on what kind of potential benefits can be achieved can be problematic.

In general, it is better to develop details of the case study in three steps with increasing levels of details in each subsequent step. This not only helps to garner support from operators and management team but also enables engineers to carry on their investigations in parallel to data collection efforts. Instead of waiting for all the data to be collected before starting the analysis, it is a good idea to start filling missing information based on best guesses from operators or based on typical values available from other steel plants or based on estimates from engineering calculations. This enables to initiate investigation and provides sense of which parameters/assumptions are critical for the study thereby helping in prioritising the data collection list.

Figure 1 summarises the major steps involved in this work process:

<u>Optimisation Stage 1 – Data Collection and Preliminary Investigations</u>

1. Define project scope based on benchmarking studies and management priorities
2. Collect plant data and process information
3. Generate heat and mass balance in the form of a simulation spreadsheet
4. Perform first phase of optimisation studies using results from the following analyses: composite curve analysis, sensitivity analysis, comparison of best practices from other steel plants, reuse/regen-reuse analysis
5. Generate an exhaustive list of potential solutions

<u>Optimisation Stage 2 – Verification of Preliminary Results</u>

6. Discuss proposed solution with Tata Steel water chemistry/treatment experts and plant engineers to find out any possible problems including pH, conductivity, spatial feasibility, capital cost etc.
7. Work closely with Tata Steel engineers in order to find ways to overcome some of these constraints. Refine and rework the details for such solutions.
8. Discard the remaining infeasible solutions

<u>Optimisation Stage 3 – Modelling and Cost Estimation</u>

9. Provide data requirements list for further modelling and optimisation work. Work out measurement plan for missing data.

10. Develop & validate spreadsheet based on non-linear models (Note that these models were used to better estimate the results for the proposed re-piping suggestions.)
11. Perform second phase of optimisation studies to workout appropriate retrofit details in collaboration with Tata Steel
12. Quantify benefits e.g. water savings, quality improvements etc. and to provide preliminary cost estimates.
13. Check feasibility of proposed solutions and discard infeasible solutions.

(Note that many of these solutions were still retained if deemed feasible for future operating scenarios such as increased production capacity and stricter environmental legislations.)

14. Perform final stage optimisation (phase 3) on promising case studies and provide more detailed cost-benefit analysis

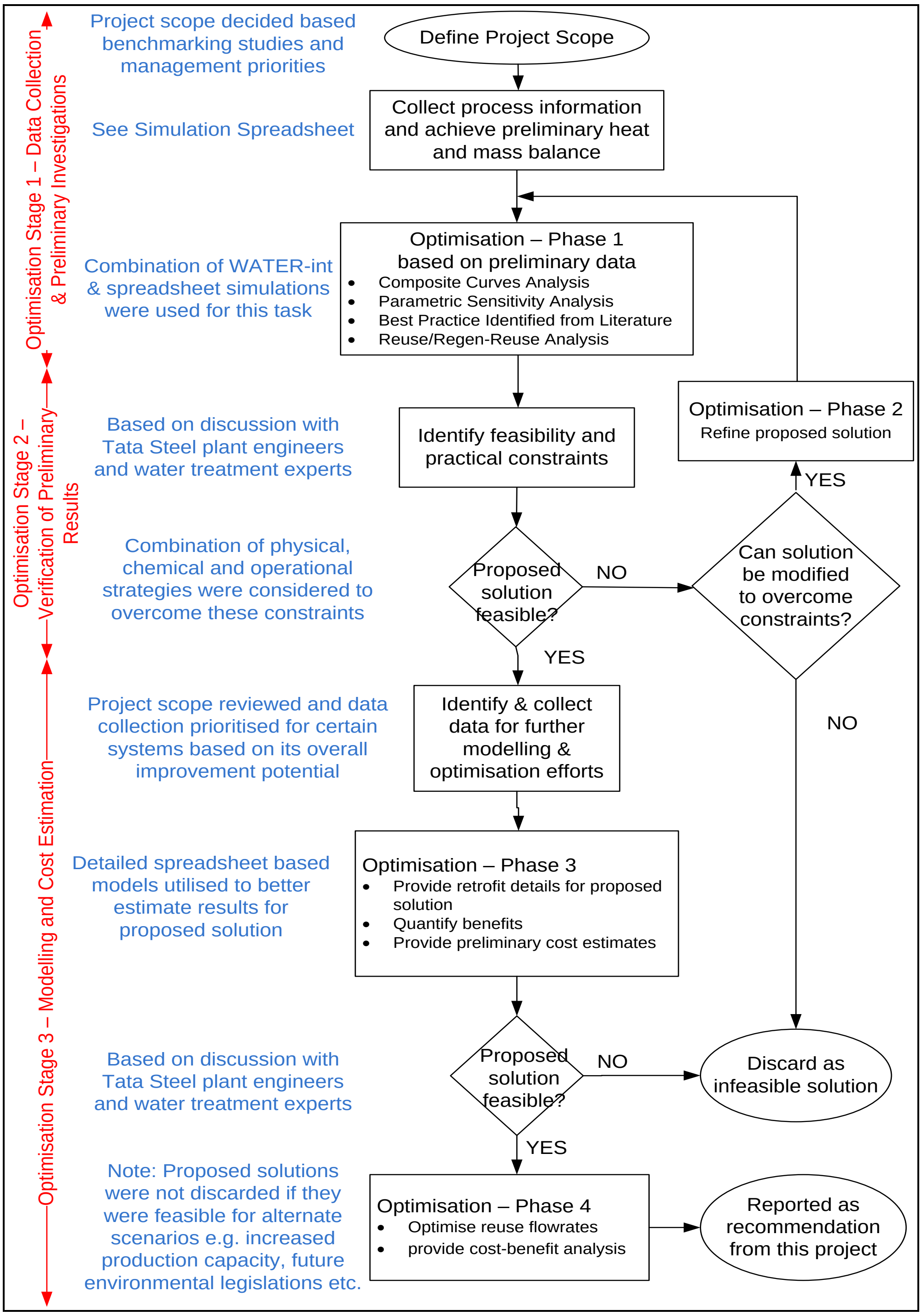

Figure 1: Three step iterative work process followed by PIL

2 General Guidelines for Case Study Development

Besides the work process discussed above, the following guidelines shall be useful to develop any case study related to water systems in integrated steel plants.

a. Data Collection

The following data sources are commonly available in steel plants and shall be reviewed to extract relevant information:

1. Legionella database

It is mandatory by regulation to monitor the water quality of a cooling tower reservoir in order to ascertain the risk of legionella disease. A cooling tower is a common element of most water circuits in steel plants including blast furnace gas washing. Thus the following useful information can be extracted from such database: Flowscheme of water circuit, typical contaminants and their concentrations, operating guidelines for cycles of concentration, maximum contaminant levels permitted etc.

2. Documentation regarding fresh water abstraction and subsequent treatment units

Fresh water abstraction records indicate the total fresh water used on site which in turn can help in estimating fresh water demand of any particular water circuit. The treatment unit design document can help in modelling and estimation of fresh water quality in terms of contaminant concentrations.

3. Discharge water analysis

Discharge water flowrate and lab analysis of contaminant concentrations is mandatory by government regulation. Thus the following useful information can be extracted from such database: permitted contaminant concentrations in waste water discharge (limits), discharge water flow variations (can be correlated with rain water harvesting), critical contaminants which are operating close to their permitted limits.

4. Pump information

Since the number of flow meters are limited on site, pumps design information and their electricity consumption logs can help determine flow rates of corresponding streams.

Besides check if any pressure, level, temperature or flow measuring instruments are in place and look for their corresponding logs.

After assessment of available information, measurement campaigns can be arranged in order to collect missing data. However it should be noted that large inventories of water are involved in steel plant water circuits and also connection between unit operations (e.g. between clarifiers and hydrocyclones) can involve cyclic transfers instead of smooth continuous transfer. Thus there are considerable transient effects that need to be nullified before achieving a valid heat and mass balance around any given system. In this regard, spot measurements need to be repeated at least three times and a flowmeter needs to be kept in place for at least one week’s time.

b. Base case simulation & validation

A number of simulation tools (e.g. Water-int, Aspen Water or other tools offered by water treatment companies) can be used for setting up and validation of the base case describing the current performance and constraints of the system. In general, the following strategy is advised for the development of simulation models in this regard:

1. Stage 1 – Data collection & Reconciliation

Excel spreadsheets are best served for this purpose. It is useful to collect data for a slightly wider scope and also to collect data from multiple sources including design and operational records in order to cross-check that numbers available are within expected ranges. Such data collection also helps in data reconciliation, validation and in setting limits for various variables.

Besides excel spreadsheets can be used collect data regarding performance of certain equipment, thereby enabling the semi-empirical modelling of such equipment.

2. Stage 2 – Simplified simulation model

Water-int is best suited for generating simplified simulation models which can be used for optimisation purposes at a later stage. Based on reconciled data, process loads and separation factors can be back-calculated and a preliminary mass & energy balance can be quickly achieved using drag-and-drop functionality of Water-Int^{TM} interface. A number of parameters might have been guessed at this point and thus sensitivity analysis can be carried out to ascertain which parameters are more critical and thereafter prioritising data collection list.

Besides, Water-int also generates composite curves which can be used for understanding system bottlenecks, setting reuse targets and identifying key contaminants.

3. Stage 3 – Rigorous simulation model

Aspen Water or other simulation tools offered by water treatment companies are best suited for this purpose. Such models need extensive data collection, however if done properly they provide predictive capability which can be used for improve accuracy of simulation results.

Such detailed model can also be used for rating mode calculation and can be utilised to benchmark equipment performance and find opportunities for machine specific operational optimisation.

Note that stage 3 i.e. development of rigorous simulation model can be skipped for feasibility studies and would be employed later while making final investment decision. If the engineering team do not have the capability to develop such rigorous models, tasks of accurately verifying the effect of the proposed solution can be delegated to water treatment companies.

c. Formulation of optimisation problem

Formulation of optimisation problem involves deciding the objective function(s), describing the system in terms of modelling equations and specifying the constraints in terms of lower and upper bound on each variable. Such formulation tasks are usually achieved by developing mathematical equations for objective function, models and constraints from scratch and coding them in commercial optimisation softwares such as MATLAB, GAMS or gPROMS.

Water-int^{TM} has simplified such tasks for MILP (Mixed Integer Linear Programming) formulation of water systems. It has a user-friendly interface to specify context specific values and the resulting mathematical formulation gets generated automatically in the back-end. These formulations can then be solved using linear and non-linear solvers within Water-int or it can be linked to GAMS solvers.

The following features are available within Water-int^{TM}:

1. Objective functions: Both flow based (minimise freshwater demand, wastewater discharge or treatment unit flow rate) and cost based (minimise operating cost, minimise annualised total cost) objective functions can be selected. These cost functions can be further modified by selectively specifying the cost coefficients.
2. Models: Both equipment models and cost parameters can be specified.
3. Constraints: Lower and upper bound can be specified for each variable considered in the formulation.

d. Translation of optimisation solutions into implementation plans

As discussed earlier, models need to be simplified in order to make them suitable for linear optimisation problems. Thus the final optimisation solution needs to be verified using rigorous simulation models. Further sensitivity analysis can be studied to fine-tune the final result for optimum results and in line with system constraints and ease of implementation. Thereafter final techno-economic evaluation can be completed to justify the implementation of the solution.

3 Case Study Specific Guidelines

CASE STUDY No 5: Lagoon 1 Water Reuse in BF Gas Wash Systems,

The lagoon water becomes an important source of reuse water if it accumulates a significant amount of rainwater. In that case, discharge water contaminant concentrations will be much lower than the limits through this dilution effect, and the reuse of such water source involves zero to low cost treatment. However the extent of reuse will vary depending upon the amount of rainfall in that region and how far the gas washing section is operated from its limits. In general the lagoon water can be reused in any gas washing section (including BF and BOS) and such strategy can result in a significant reduction in water footprint of the site.

CASE STUDY No 6: Pond A Water Reuse in BF Gas Wash Systems

The Blast furnace gas washing (BF GW) circuit is a major contributor of ammonia. Hence containment of blowdown from the BF GW circuit will help in achieving a significant reduction in ammonia levels in the final discharge water. Thus blowdown reuse should be maximised at every recycle opportunity i.e. first in the hydrocyclone section and then in the settlement lagoon (Pond A). In general, the following sources are good candidates for BF GW water utilisation: slag granulation unit, sinter plant and bowsering stations.

In general, low cost ammonia reduction strategies can be uncovered through such studies.

CASE STUDY No 7: Recycling of the BF GW hydrocyclone overflow water with suitable treatment

The gas washing section of the blast furnace collects significant amounts of iron (866 kg/h iron for 3 Mt/y of steel production capacity). However this iron cannot be reused if not collected selectively by separating the zinc and lead from it. Around 70-80% of this iron can be recovered by using hydrocyclones. Thus they should be the first equipment that is considered for iron recovery. Second step would be to add a magnetic filter which can recover the remaining 20-30% of the iron in the BFGW blowdown stream.

In general, these case studies involve low-to-medium capital investment and the payback period can be extremely attractive if good quality iron can be recovered from them. Thus the design of the hydrocyclone and magnetic filter are critical for the success of such case studies. Also such solutions improve water quality in both gas washing section and waste water discharge.

CASE STUDY No 8: HPM-Ancholme System Water Recovery & Control

This case study highlights the importance of communication between multiple pumps operating within the same system. Improper settings of level control and lack of communication between pumps can lead to pressure fluctuations, loss of pressure in water mains, wastage of pumping electricity, and lost opportunity of water recovery from reuse sources. Time based dynamic simulation of such systems and fine-tuning of level settings & control strategies can prevent the above mentioned issues. Such simulations are not complicated and can be replicated in excel spreadsheets for analysis purposes. The resulting control strategy can then be implemented using PLC based automated control system which is a relatively low cost solution.