Chapter 1: Introduction

1.1. Background

Sasol experiences high fouling rates in heat exchangers that use process/plant cooling water as cooling medium. The main reason for this is that the cooling water used in the heat exchangers is kept in a closed loop system resulting in the rising of sediment concentration levels.

Sasol also has a problem with water supply shortages. The water that is available in the region is not fit for industrial use due to high sediment and other impurity concentrations; consequently, other sources have to be investigated.

At Sasol, hydrocarbons are extracted from coal and natural gas through the Fischer-Tropsch process which also produces carbon dioxide, mercury, sulphur, slag (the latter three are only applicable to coal) and water (US Department of Energy, 2011; Chaney and Van Bibber, 2006:34). The water produced currently provides part of the cooling water within the process cycle. The demand, however, is still not met.

Along with the water supply shortage, several other problems occur that affect the cooling water and its characteristics. The water that is produced in the gasification process is contaminated. The by-products from the gasified coal, such as slag, char and ash, are, to some extent, entrained in the fluid stream. This sediment mixture is thought to be the main cause of heat exchanger breakdown that is found within the cooling water cycle.

The water shortage adversely affects the pressure and, in turn, the flow rate at which the water can be delivered to the cooling water stream. Because of the low flow velocity, the sediment does not stay suspended; heat exchangers in the system thus experience particulate fouling from the entrained sediment.

In verbal communication with Lombaard (2011), the author was informed that leaks within the system cannot be fully controlled. All along the process stream, the possibility of leaks occurring from a higher-pressure process stream to the lower-pressure cooling water is large, contaminating the water with hydrocarbons or other process fluids. The addition of these unknown quantities of fluids adversely affect the quality of the water and reduce the predictability of the fluid, flow and heat transfer characteristics of the heat exchanger due to density and viscosity variations.

1.2. Need

Lombaard (2010) informed the author that the addition of sediment into the cooling water stream creates particulate fouling problems within the shell-and-tube heat exchangers (STHEs) that are used for the cooling of several process liquids. The reduced cooling water flow rate through the shell-side of the heat exchangers makes the possibility of particle suspension improbable, leading to particulate fouling of the heat exchanger. The particles build up and reduce the flow area to the point of being fully blocked. This results in the replacement of tube bundles every nine months. A solution is required that can increase the lifetime of the heat exchangers without implementing an additional water treatment facility or finding other viable sources of water.

1.3. Scope

This study will analyze the effects of baffle and tube configurations on sedimentation rates in the shell-side of an STHE by means of computational fluid dynamics (CFD). Finding a solution for the sedimentation problem at hand will not form part of the scope for this study. Only recommendations on possible solutions will be discussed at the end of the text.

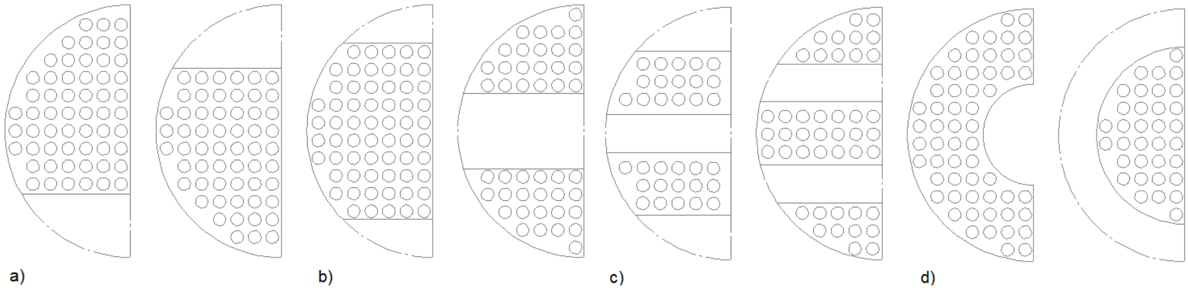

Figure 1: Baffle configurations

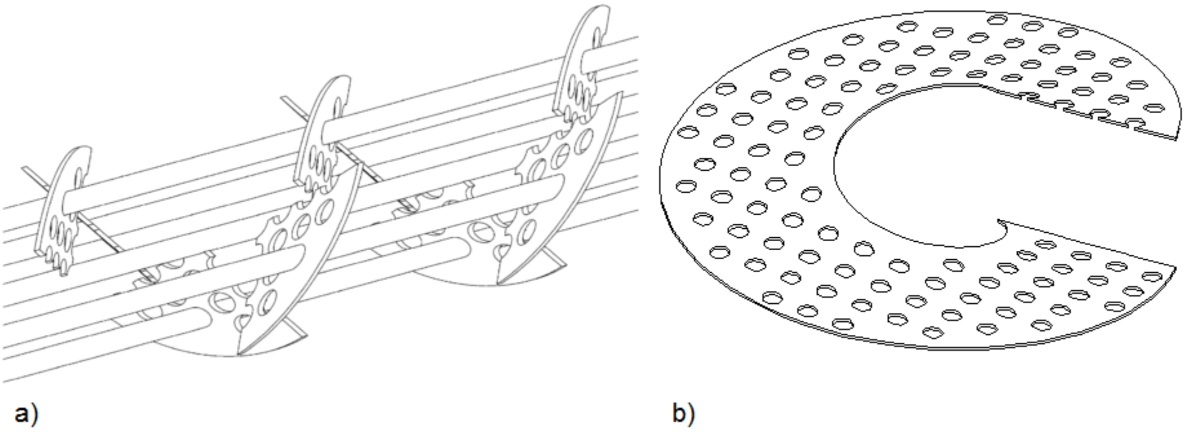

Figure 2: Helical baffles

Many different shell-and-tube baffle designs are available in open literature and some are specifically discussed in the Heat Exchanger Design Handbook no. 4 (Bell *et al.,* 1983b). Of these designs, five configurations (Figure 1a-d and Figure 2a-b) can be investigated. They include single-segmental baffles (which are currently implemented at Sasol), double-segmental and triple-segmental baffles, disc-and-doughnut baffles and helical baffles. This study will, however, only focus on the effects of single-, double- and disc-and-doughnut baffles. According to Lombaard (2011), as well as Krishnan and Kumar (1994), triple-segmental baffle configurations within Sasol have been found to be prone to tube vibration and subsequent failure. Helical baffle STHEs are possibly the most effective shell-and-tube-type heat exchangers that are currently available due to the nonexistent recirculation regions behind baffles (Jafari Nasr & Shafeghat, 2008:1332; Lei *et al.,* 2008:4386), but the technology regarding these baffles is mostly of a proprietary nature. Due to financial reasons, the implementation of helical baffles is impractical. Lombaard (2011) is of the opinion that the current sole supplier of helical baffles has a monopoly with respect to the manufacturing cost, resulting in larger financial strain for Sasol in comparison to the current maintenance strategy.

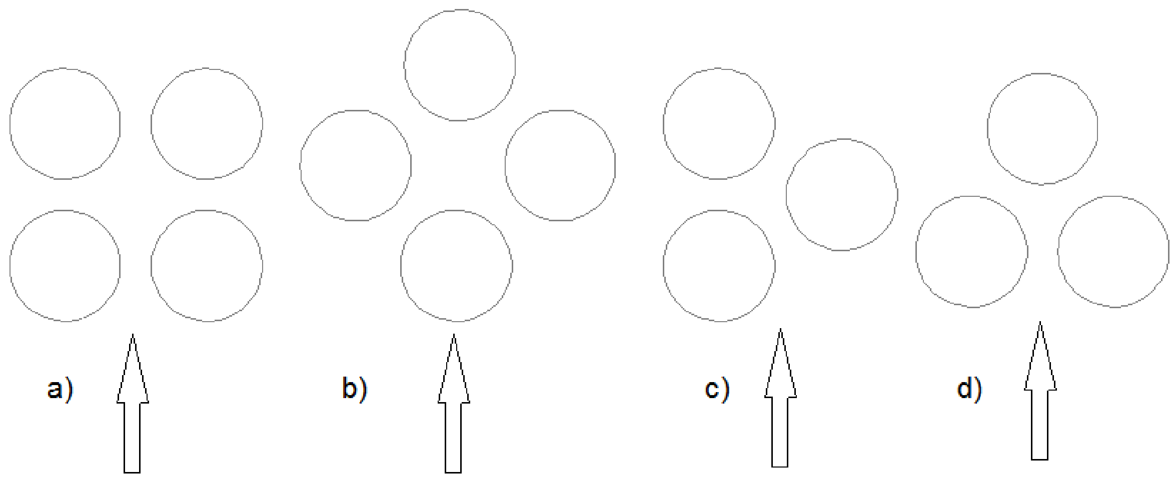

Figure 3: Tube configurations

Four basic tube configurations are applicable within an STHE. The four configurations comprise combinations of the rotated and inline, as well as triangular and square tube arrangements. In Figure 3a) to d) above, the tube combinations are as follows: square (90°), rotated square (45°), triangular (30°) and rotated triangular (60°). The inflow stream direction is taken as the angle reference. According to Yanez-Moreno and Sparrow (1987:1995) as well as Nishimura *et al.* (1993:563) and Khan *et al.* (2006:4838), the inline array is the most efficient concerning pressure drop, thus internal fluid velocities will most likely be the smallest in these configurations. The present study will only consider square and rotated triangular arrangements (Figure 3 a) and d)) in order to keep the scope of the study within realistic bounds.

The temperature distribution and the heat that is transferred throughout the heat exchanger will not be simulated. The complications regarding the solution of the energy equation, together with the current turbulence model, number of computational cells (size of the simulation mesh) and intricacy of the geometry are deemed to be too strenuous and consequently fall outside the scope of the study.

1.4. Methodology

The methodology of the study was as follows:

- **Literature survey** – A review of open literature, concerning all relevant aspects of the study. Several of the relevant issues under discussion are
    - CFD in general;
    - general simulations of heat exchangers;
    - CFD simulations of STHEs;
    - the effect of tube and baffle configurations on STHEs;
    - the effect of leakages on the heat transfer characteristics of STHEs;
    - combating leakage in STHEs;
    - shell-side pressure drop calculations and correlations;
    - ideal tube bundle pressure drop and flow characteristics;
    - turbulence model variations, comparisons and applicability within the simulation of STHEs; and
    - the simulation of multiphase flows.

- **Theory** – Information from the literature survey, in whatever form, may also be relevant in terms of the theoretical background of the study. A deeper understanding of the theoretical principles that are employed within CFD software is required to enable the correct application of the software throughout the simulations.

- **Simulations** – Once the theory and rationale behind the simulation details were finalised, the full set of simulations could commence. The simulation stages comprised the designing of the STHEs with the set of chosen configuration modifications, a simulation setup of the configurations within STAR-CCM+, mesh generation and flow field simulation. In the second simulation phase, the aim was not only to solve the flow field, but also to incorporate the modelling of sediment transport and deposition within the model that is currently implemented at Sasol, and the steady-state configuration having the best performance. Validation of the simulation procedure was attained by comparing numerical and experimental results of studies on sedimentation tanks. The simulations were performed on the North-West University's high-performance computer (HPC). The HPC cluster consists of 70 nodes (separate smaller computers), each with high-end processors with random access memory (RAM), ranging between 10 gigabyte (GB) and 32 GB. Two 32 GB RAM nodes with two Intel Xeon, eight core 2,7 GHz processors were used in this study due to the models' intricate geometry that requires large numbers of computational cells and resources. An Intel Core I7 processor with 24 GB RAM personal computer was also used to complete the basic simulations.

- **Examination and discussion of the results** – Results of the simulation were extracted from the simulation files and imported into an Excel spreadsheet. Visual representations of the flow velocities and particle concentrations form part of the results that were presented. Specific data that were extracted are the flow velocities within the bypass stream, recirculation and baffle cross-flow regions, the pressure drop over the heat exchangers and flow fraction results throughout the geometry. Because of the increase in computational time, thermal distributions within the heat exchanger were omitted. The most promising combination of tube and baffle arrangement was chosen for the second set of simulations, i.e. multiphase modelling.

- **Conclusions and recommendations** – In the final chapter of the study, conclusions regarding the flow field, velocity and sedimentation areas are drawn. Discussion and conclusions regarding the configuration showing the best improvement for the problem under consideration are made. Recommendations are also made regarding future work in other areas of relevance that were left out of the current study, but which can add value to the solution of the problem. Recommendations regarding problem solution possibilities are also discussed.

1.5. Conclusion

This chapter presented an overview of the current study. The background information leading to the need for the study was discussed and the scope was described. The scope describes the main topics that was investigated and is followed by the method for completing the investigation successfully.