CHAPTER 1

INTRODUCTION

The augmentation of heat transfer over surfaces is accomplished readily with the inclusion of dimples on the heat transfer surfaces without appreciably increasing the friction factors and pressure drop. Studies reported that heat transfer augmentation of as high as 150-250% was found when compared to flat heat transfer surfaces, together with pressure losses of about half of that of conventional rib turbulators.

Dimple plate heat exchangers were initially designed for use in the food and wine industry. The implementation of these heat exchangers in industrial conditions came with more challenging operating conditions and more critical consequences.

1.1. Dimpled plate heat exchangers

Dimpled plate heat exchangers or thermo-plate heat exchangers (as named by the manufacturers), represent a special panel heat exchanger form, with its panels being welded together and expanded, rather than just being bolted together as in normal panel heat exchangers. The elliptical flow ducts illustrated in Figure 1 and the resulting transient flow patterns increase the turbulence of the flow over the dimpled plate.

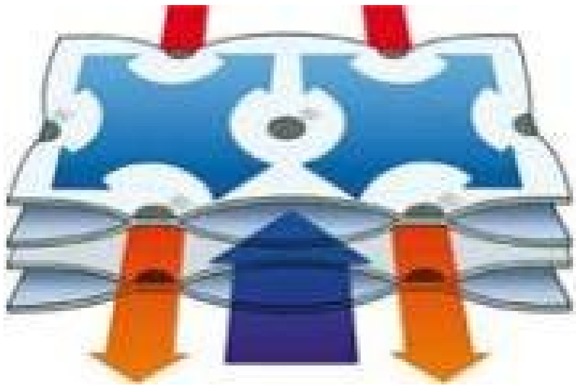

Figure 1: Flow structure in and between the dimpled plates (DEG Engineering: Heat Exchanger Systems)

According to the manufacturers, the design provides a number of benefits during operation:

- Low susceptibility to fouling due to the hydrodynamic structure of the dimples.
- Any flow pattern can be delivered, which includes genuine counter flow, parallel flow and cross flow or any combination of these.
- Design can be adapted to fit in the restricted space for special applications.
- Any cold-workable high-quality steel can be used for the manufacture.

In this case the dimple plate heat exchangers were designed to be counter flow surface condensers to be installed in the top of distillation columns.

The function of the condenser in a distillation column is to condense the overhead product, of which a part is returned as reflux to the top of the column. Normally this is done by a condenser of a shell-and-tube or spiral configuration at ground level.

Figure 2 illustrates the typical mounting configuration of the DEG surface condensers inside the top of a distillation column. With this design no other condenser is needed. This arrangement reduces the footprint area required by the distillation column, the pressure drop and the complexity of the system.

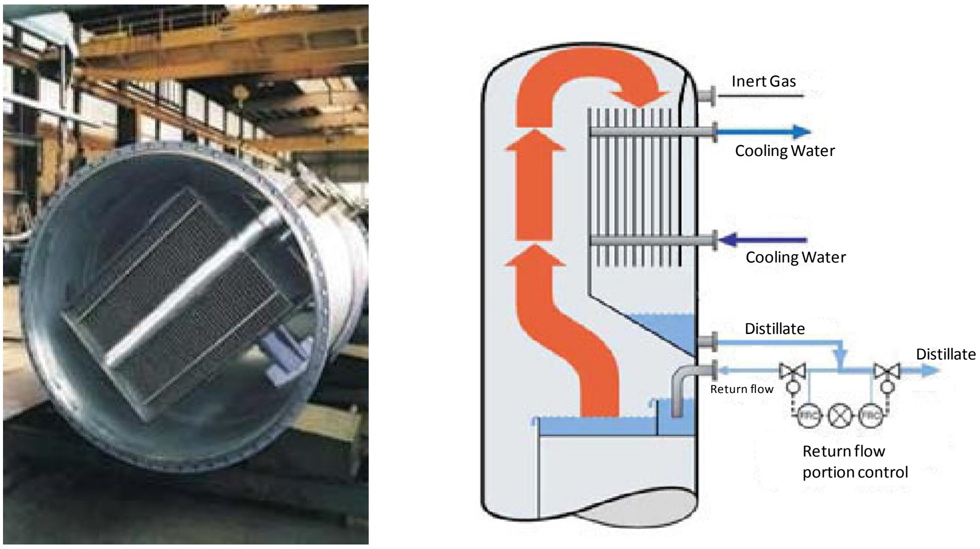

Figure 2: A typical DEG head condenser mounted in a column. (DEG Engineering: Heat Exchanger Systems)

The production technique used to construct the heat exchangers determined a number of important characteristics that influenced the structure, vibration response and the possible modes of failure due to excessive vibration of the heat exchanger.

1.2. Manufacturing process

To manufacture the heat transfer panels, the correct material is selected and two sheets are resistance-welded in the pattern of the required dimples. This pattern will be the pattern of the dimples on the panels. The outside rim of the sheets is seal-welded and other internal sealed sections are created where spacing bolts can be added to stiffen the structure. At this stage the number of spacing rods is fixed and holes for the spacing rods are drilled.

A hydraulic cold forming process expands the internal volume between the individual sheets, while the welded points and seams remain together. This process creates the final dimpled shape of the panels illustrated in Figure 3.

Figure 3: The dimple structure on individual plates

A number of panels (as required by the design) are then assembled to form the heat exchanger core. The individual panels are connected with bolts through the spacing holes, with spacers determining the spacing between the individual panels.

If the designers expect problems with excessive elasticity, additional bolts are added to stiffen the core further where needed; a typical spacing bolt assembly can be seen in Figure 4. As stated earlier, these holes should be drilled before the panel shaping process in special sealed sections of the plate.

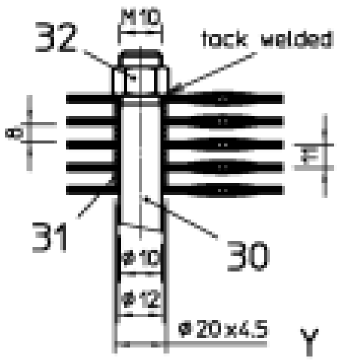

Figure 4: An extract from the design drawing, showing the spacer bolt assembly (Appendix C)

After the core has been assembled, the top and bottom header must be welded to the panels. Due to the fact that high alloy stainless steel (mostly austenitic or super austenitic stainless steels) is often used due to process corrosion requirements, the heat exchanger core has already been assembled and a leak-free seal is required. A specific welding process is used.

The welding process begins with the cutting of notches into the inner half of the header pipe as described by Figure 5. The plates are then welded to the notches in the header pipe from the inside where the quality of the weld can be better controlled and non-destructive tests can easily be performed.

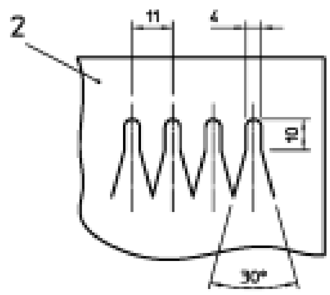

Figure 5: An extract from the design drawings showing the notched cut into the bottom half of the header-pipe (Appendix C)

The header pipe is then sealed by welding the outer half of the header, with inlet/outlet pipe, onto the inner half. The resulting weld is indicated in Figure 6.

Figure 6: A photograph of the bottom header showing the weld line where the two halves of the header were welded together. The bottom guide frame and u-shaped guides are also visible

After the heat exchanger core is finished, the rest of the structural components are welded to the top and bottom headers. This includes the shroud (a metal channel that encloses dimple plates), the guide frame (the structure onto which the top and bottom guides are fitted) and the heat exchanger mounting system to the top header and a guide frame to the bottom header.

Figure 7 and Figure 8 illustrate the U-shaped guides that are attached to the guide frames to support the edges of the plates in a number of locations.

Figure 7: A photograph of the bottom guide frame assembly

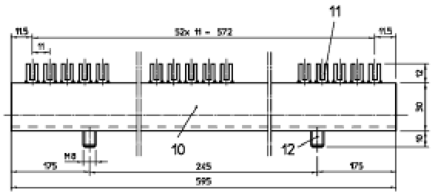

Figure 8: An extract from the design drawing showing the U-shaped guides for the sides of the panels. These structures are bolted to the shroud (Appendix C)

The finished heat exchanger is then transported from Europe to South Africa where it is mounted in the condenser column assembly by the column supplier.

The current design of the column, illustrated in Figure 9, requires that the top structure of the condenser is bolted tightly to the column internals. The top header is welded to the inlet pipe for the cooling medium.

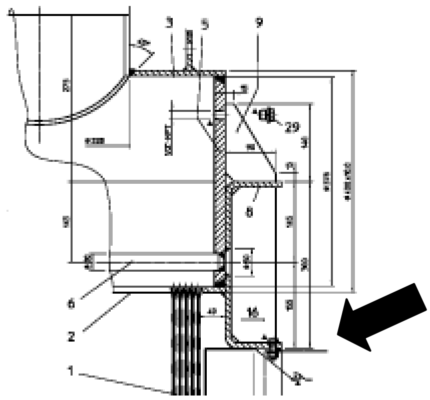

Figure 9: Current mounting system of condensers in the distillation columns (Appendix C)

The bottom of the heat exchanger is free to move independently of the top structure, with only the plates connecting the top and bottom headers. This was done to negate the effects of thermal expansion, which could cause excessive stresses in the structure. The bottom header is connected to the outflow pipe by an expansion joint or a bellows.

After the condenser has been installed in the column, the distillation column is transported to site in sections. These sections are assembled and sealed with the only access to the internals via manholes. This makes the replacement of the column-top condensers very difficult and the reliability of these heat exchangers is therefore very important.

1.3. Operational history in SASOL

The DEG thermo-plate head condensers were first imported by DB Thermal (the agents at that stage) and were installed at the gum removal plant at Secunda in 1999. These units had worked without any problem up to 2008.

On account of the success in these applications more units were installed, in, amongst others, the Octene 2 plant at Sasol Solvents in Secunda. Two of these units failed within the first six months of operation. After six further failures, all the units were replaced by new condensers.

The removed heat exchangers were to be subjected to metallurgical analyses to determine the cause of failure, but these tests were never concluded due to the toxic and flammable deposits in the heat exchangers.

In the replacement condensers the tack welding of the u-shaped guides was omitted. This enabled the guides to slide along the plates when either the plates or the structure would thermally expand or contract.

The visual examination of the failed exchangers removed from the Secunda plant indicated damage around the bottom header, as illustrated in Figure 10. The welds between the plate pack and the bottom header had failed, thus causing leakage of the cooling medium into the distillation column.

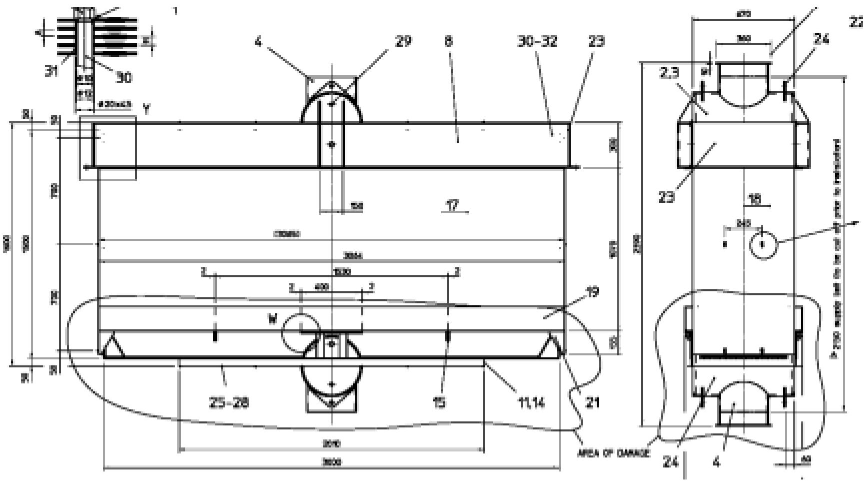

Figure 10: An excerpt of the drawing showing the area of damage of the heat exchanger (Appendix C)

As Sasol was interested in implementing column-top condensers and the dimple plate heat exchanger technology in general in more plants and processes, these failures (and the costly replacements), created a significant risk that had to be mitigated. There were a number of possible reasons proposed for the failure; these included thermal expansion (as corrected by design changes) and fluid-induced vibration.

DEG has had problems with vibration leading to failures of the dimpled plate heat exchangers in other applications. Because of these problems, the manufacturers increased the stiffness of the heat exchangers larger than an arbitrary size and flow rate with additional cross-linkages during the manufacture of the vessel.

The manufacturer’s mitigation measures are not based on any scientific study of the vibration response of a dimple plate heat exchanger during operation. Therefore, the actual risk and mitigation measures are still largely unknown and addressed in a hit-and-miss fashion.

The author was therefore requested to evaluate the possibility of fluid-induced vibrations causing damage in dimple plate heat exchangers and propose a feasible design concept to minimize the damage caused by fluid-induced vibrations if it were found that they occurred in practice.

1.4. Scope

The scope of the study is to determine the nature of flow-induced vibration in dimple plate heat exchangers and produce a working concept to reduce the dynamic forces in the internal components of the heat exchanger that can be implemented for any dimple plate heat exchanger under its specific operating conditions and structural attributes.

1.5. Methodology

The scope as described in the previous section was divided into a number of logical steps to ensure the logical completion.

The nature of fluid-induced vibrations were determined from both the available scientific literature (Chapter 2) and due to certain limitations (as discussed in Section 2.3) using a qualitative experimental method (Chapter 3).

Once the nature of the vibration was determined a number of vibration control concepts were evaluated for effectiveness and practicality in this case (Chapter 4).

Mathematical models (Chapter 5) were constructed from theory and an experimental test setup was designed to simulate the structure of the column-top condensers (Chapter 6).

Once all the relevant parameters for the mathematical model were characterized for the experimental test setup (Chapter 7), the theoretically predicted values (Chapter 8) could be compared to the actual measured values with and without the vibration control concept (Chapter 9).

Through this process the effectiveness of the vibration control concept and the accuracy of the mathematical models could be evaluated.