

MECHANICAL REDESIGN OF ION EXCHANGE RESIN VESSEL BOTTOMS AT HULETT REFINERY

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Abstract

A third party inspection failure of one of the flat bottom resin vessels, combined with repeated failures of the lateral distribution system collecting the exiting liquor, caused the mechanical and process design of these vessels to be reviewed. This has resulted in modifications to the fabricated flat bottom design and the replacement of the lateral distribution system with a stone fill and top hat distribution design. This paper discusses the causes of the mechanical failure, modifications implemented and the benefits experienced after redesigning some of the ion exchange resin vessels at Hulett Refinery, which include a lower pressure drop and higher throughput.

Keywords: ion-exchange resin vessel, structural design, liquid distribution, stone bed

Introduction

Hulett Refinery ion exchange decolourising plant consists of two sets of vessels, the primary and the secondary vessels. Brown liquor from the carbonatation plant entering the ion exchange decolourising plant is split into 5 parallel streams as it flows through the primary vessels, into a combined buffer tank. From here it splits again into 5 parallel streams and is pumped through the secondary vessels. These streams combine once again before being pumped to the rest of the process. The combination of two parallel streams in series allows for flexibility, because if one of the vessels needs maintenance the other nine can still be used. If the primary and secondary vessels were connected in dedicated pairs two vessels would be down if one needed maintenance (Figure 1).

The original four primary vessels have concrete filled torispherical dished ends to create an artificial flat bottom. The fifth, which was added later, has a fabricated mild steel (boiler plate) flat bottom only. The inside of the vessels including the top of the concrete were coated to provide protection from the products in the vessels.

The original Lateral Distribution System (LDS) was installed on the artificial flat bottoms of the Concrete filled Dished End (CDE) vessels. The original distribution system consisted of a central pipe, branch collection pipes at right angles with small holes and channel beams for supporting the branch collection pipes (Figure 2). The branch collection pipes are covered with a matrix mesh that is covered in turn with filter cloth. The matrix mesh and filter cloth allows the liquid to enter the collection pipes but prevents the ion exchange resin beads from entering.

Due to the difficult and time consuming process of setting the concrete in the CDEs, as was done on the first four primary vessels, it was decided that fabricated flat bottoms, as per the fifth primary vessel, should be installed for the secondary vessels together with the same LDSs (Figure 2).

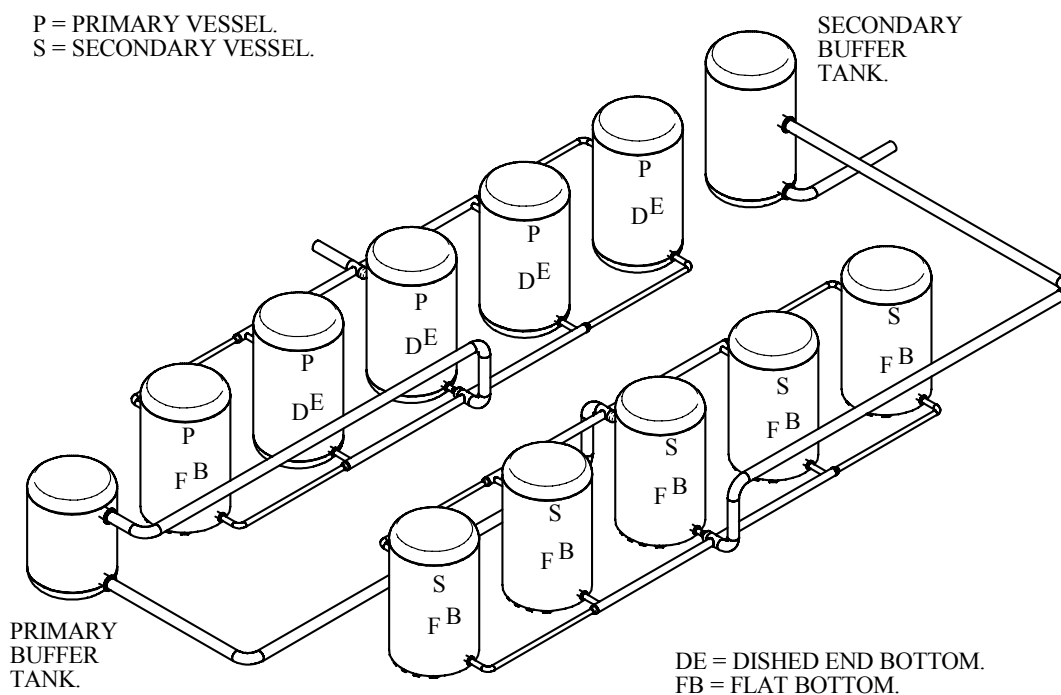


Figure 1. Diagrammatic layout of original ion exchange decolourising plant.

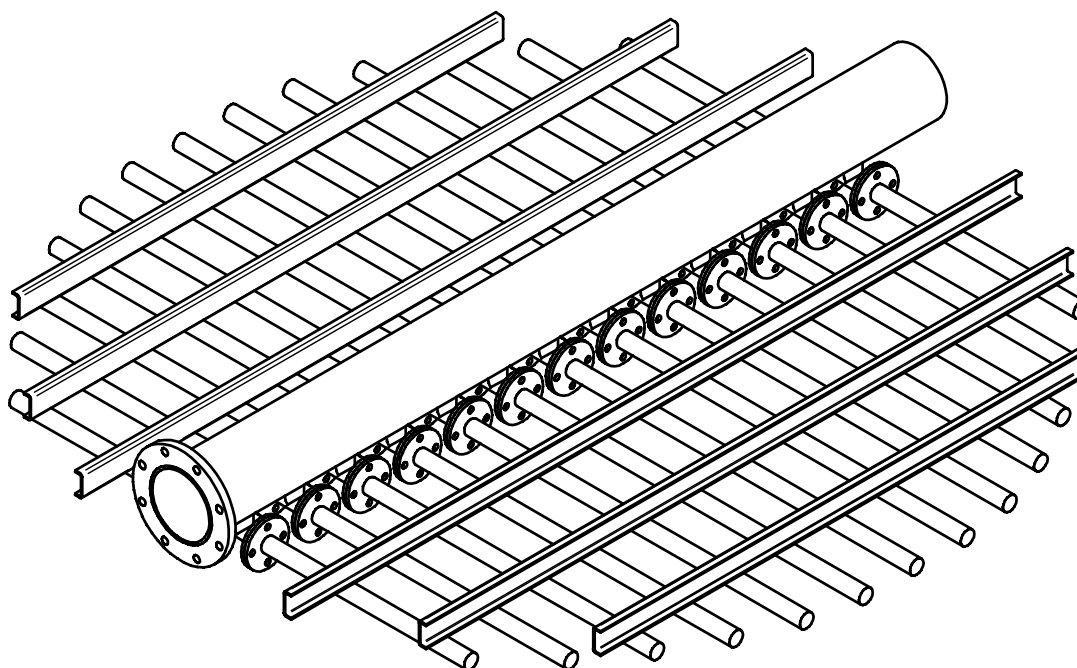


Figure 2. Isometric view of bottom lateral distribution system.

Problems

Repeated failures occurred on the LDSs fitted to the fabricated flat bottom vessels. These failures included bending of the distributor pipes and support channels, rupture of pipes, failure of the filter cloth and tearing off of the support lugs from the vessels cylindrical wall.

Later, one of the vessels with an Original Fabricated Flat Bottom (OFFB) (Figure 3) failed a statutory third party inspection by an approved inspection authority. A design check was done using Finite Element Analysis (FEA) and this indicated that excessive stresses existed in the shell above and below the bottom plate and support steel work of the flat plate. (See Appendix A for comments on the FEA and the third party inspection.)

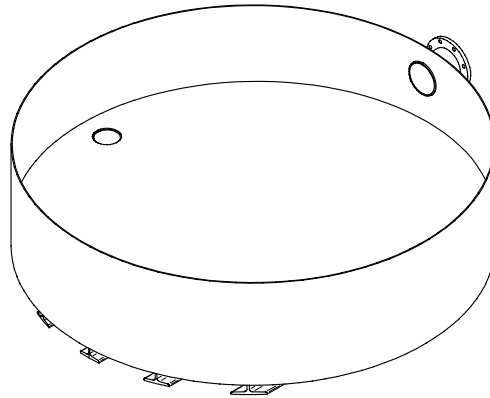


Figure 3. Typical layout of the original fabricated flat bottom.

No distributor failure occurred on the primary vessels with the CDEs from 1978 to 1999 however, failures started to occur on these bottoms after 1999. When one of the distribution systems was changed on this type of vessel, it was found that the top layer of concrete with an epoxy additive was severely corroded under the protective layer (Figure 4).



Figure 4. Corroded concrete.

Discussion of failures

Two theories on what could be the cause of the failures of the LDSs were put forward and were discussed at Tongaat-Hulett Sugar.

The first theory is that the failure is caused by the physical expansion and contraction of the resin beads during the process cycle, which results from by the different product streams that are in contact with the resin. These streams included the liquor, resin regenerating solutions and water. The theory is that the resin beads get stuck between the bottom of the vessel and the LDS. This happens when the beads are at their smallest possible size. When the beads expand during later parts of the cycle they cannot escape from underneath the distribution system, this causes the beads to apply equal forces to the laterals of the distribution system and the bottom plate, which results in the failure of the LDSs.

This theory becomes suspect when the failure rates of the LDSs in the CDEs are compared with the failure rate of the LDSs in the Original Fabricated Flat Bottom (OFFB). For the theory to hold, the failure rates should be the same for both types of bottom but big differences have been experienced (Table 1).

Table 1. Comparing type of vessel and type of distribution system with failure rate.

Type of vessel bottom	Year installed	Distribution system	Failure rate (Period: Number/year/vessel)
Concrete filled torispherical dished end (CDE)	1978	Horizontal pipe system (see Figure 2)	1978-1999: 0 1999-2002: 0.8
Original fabricated flat bottom (OFFB)	1987	Horizontal pipe system (see Figure 2)	1987-1989: 0 1989-1999: 0.72 1999-2002: 2.7
Redesigned fabricated flat bottom (RFFB)	1999	Horizontal pipe system (see Figure 2)	18 month period: 0.67
Redesigned fabricated flat bottom with top hat and stone bed (RFFB+THSB)	2001	Top hat plus stone bed (THSB) (see Figure 3)	None
Torispherical dished end with top hat and stone bed (DE+THSB)	2002	Top hat plus stone bed (THSB) (see Figure 4)	None

The second theory is that the deflection of the bottoms is the cause of the failures of the lateral distribution system. This theory is substantiated by the failure rates in Table 1 and the calculated deflections shown in Table 2. It can be seen that the failure rate is the highest on the vessels with the highest calculated deflections.

Comparing Tables 1 and 2, the question arises why the increase in failure rates of the LDSs on both the CDEs and the OFFBs occurs. It was found, during a statutory third party inspection when one of the OFFBs failed this inspection that the OFFB weakens due to metal fatigue and then starts to deflect more than the calculated values. It was also found when converting one of the CDEs to a torispherical Dished End (DE) with “Top Hat” and Stone Bed (THSB) system that the top 150 mm of the concrete was severely corroded and that it would be flexible under the operating pressure of 450 kPag. The increase of failures of the LDSs when the bottoms weaken and flexing increases, confirms this theory.

Table 2. Comparing calculated deflection of different bottoms.

Type of vessel bottom	Year installed	Calculated deflection at operating pressure
Concrete filled torispherical dished end (CDE)	1978	None Deflection suspected, magnitude unknown
Original fabricated flat bottom (OFFB)	1987	4.21 mm
Redesigned fabricated flat bottom (RFFB)	1999	2.47 mm
Redesigned fabricated flat bottom with top hat and stone bed (RFFB+THSB)	2001	2.47 mm
Torispherical dished end with top hat and stone bed (DE+THSB)	2002	No deflection calculations done. None required

Action and solutions

The failed OFFB was replaced by a RFFB. Appendix B provides comments on the FEA of the RFFB and reasons for its selection. Deflection indicators were installed below all the other OFFB vessels to enable a continuous monitoring of the integrity of all the remaining original bottoms. Fatigue failures of the remaining OFFBs are expected at random.

Redesigning started on the distribution system after it failed in the vessel with the RFFB. It was decided to use a system similar to the one in operation at Afprod Glucose plant in Germiston, which had given no problems since installation. This system, THSB, consists of a “top hat”, layers of graded stone above the “top hat” to form a stone bed and then the resin above the stone bed. The “top hat” installation forms the new collection point of the bottom distribution system. The stones form a filter that prevents the resin beads from escaping through the “top hats”. An additional strake was added to the bottom of the resin vessel to increase the height and volume, to compensate for the loss of resin volume created by the stone fill. A “top hat” installation with four “top hats” (Figure 5), was done on a spare RFFB before it was installed on one of the secondary vessels.

An increase of the failure rate of the distribution system in the primary vessels with the CDEs prompted a redesign of the distribution system in the vessels with these bottoms. A single large “top hat” was installed at the bottom of the dished end (Figure 6). The height of the vessel was also increased to allow for the loss of resin volume created by the stone bed that was loaded above the top hat.

The new stronger fabricated flat bottom has removed the structural risk of failure but at considerable expense. It was however the most cost effective solution at the time when the old fabricated bottom failed the statutory inspection. The installation of the “top hat” and stone bed distribution system has solved problems experienced with the lateral distribution system. In addition, it has reduced the pressure drop across the vessel. This has allowed a reduction in the feed pressure above the resin from 450 to 320 kPag. No problems have been experienced on the new “top hat” and stone bed distribution system, which has worked well with the new fabricated bottom and has run now for a over a year without any maintenance being required.

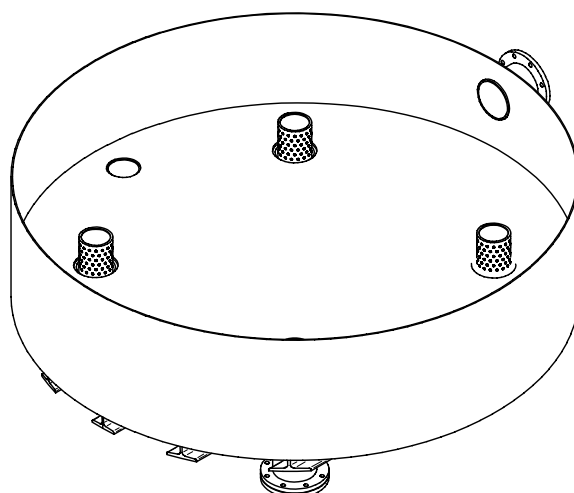


Figure 5. Redesigned fabricated flat Bottom with four top hats installed (stones omitted for clarity).

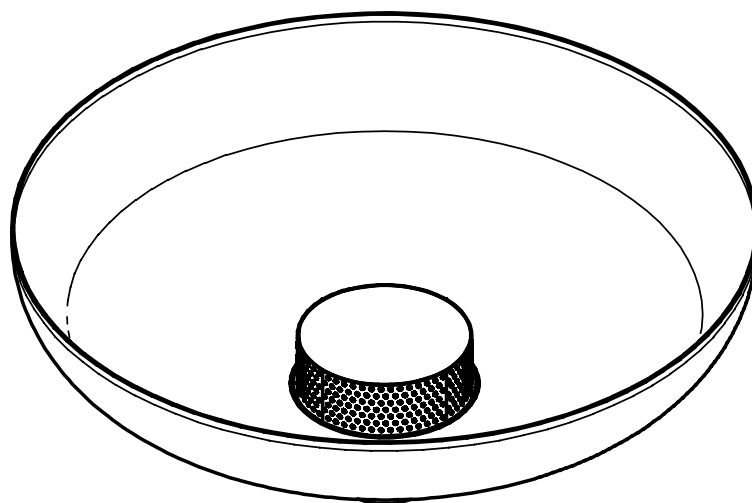


Figure 6. Torispherical dished end with a single top hat installed (stones omitted for clarity).

Results and Conclusions

Replacement of the original fabricated flat bottom with a dished end, fitted with a “top hat” and stone bed, has removed the structural risk while retaining the improved hydraulic characteristics. Less power is required to obtain the same flow rate through the vessel at the lower internal pressures. The torispherical dished ends are also cheaper than a redesigned fabricated flat bottom. Further, the “top hat” and stone bed does not require a flat bottom either fabricated or artificially created, which removes problems of setting concrete in a torispherical dished end and the higher cost of the redesigned fabricated flat bottom.

The dished end, fitted with a “top hat” and stone bed, is now the preferred choice of bottom and distribution system at the Hulett Refinery. This installation runs under a lower pressure, which increases the safety factor on these vessels. The operation of these vessels under lower pressure requires less power and less compressed air for operation. The installation cost of this system is also less than that of the redesigned fabricated flat bottom. A program has therefore been put in place to change all vessels to a dished end bottom with a single “top hat” and stone bed as per Figure 6 over time or when failures occur.

APPENDIX A

Finite element analysis of original bottom and third party inspection

A FEA was done on the original fabricated flat bottoms to determine the expected deflections under normal operating pressure and test pressure. This FEA indicated very high stresses in the shell and support beams, as high as 280 MPa, which exceed the allowable stress of 150 MPa for “boiler plate” (BS1501-151-430A) up to a thickness of 40 mm and below a temperature of 100°C as specified in (BS5500: 1999 Specification for fusion welded pressure vessels). These high stresses indicated that a redesign of the bottom would be required.

Third party inspection of failed vessel

Due to the complexity of the OFFB, assumptions had to be made to do the third party inspection, when it was legally required. The easiest way to inspect the integrity of such a bottom is to measure the deflection in the centre of the bottom during a pressure test.

The L/600 rule for load bearing beams in the crane and rigging beam codes were used to determine the maximum deflection under operating load. A deflection of $\pm 12\text{mm}$ was measured in the centre of the vessel that should have been less than 4.66mm for a span of 2800mm (the diameter of the vessel). This clearly indicated that the structural integrity of the vessel had reduced to below acceptable levels.

The FEA

A numerical model was generated using MSC visual Nastran. This model was meshed, loaded with operating and test pressures, constrained and analysed. Figure A1 shows the calculated Von Mises stresses on the bottom when the operating pressure is applied, which is typical of all the plots obtained, during the analysis of the various options. The calculated deflections and maximum Von Mises stresses are shown in Table A1.

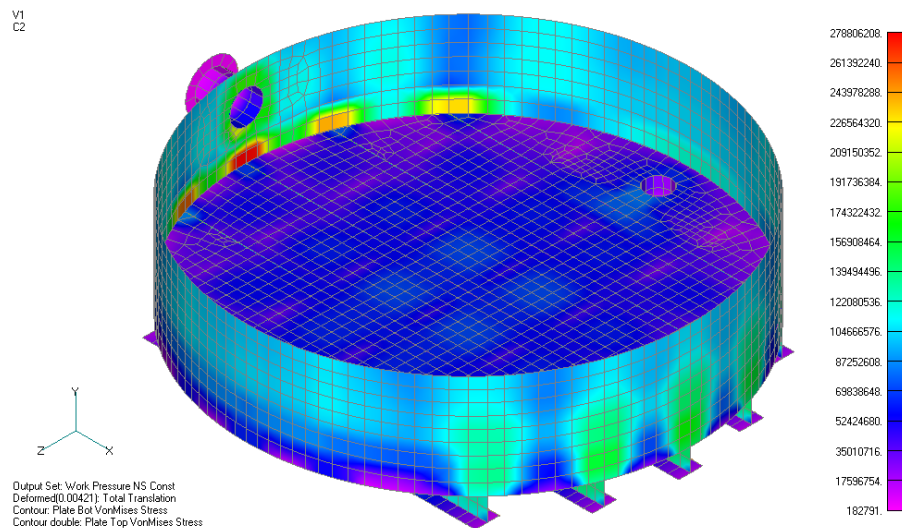


Figure A1: Von Mises stresses in original fabricated flat bottom (operating pressure applied).

Table A1: Calculated results from FEA.

Applied pressure	Calculated deflection	Maximum calculated Von Mises Stress	Maximum allowable design stress
454 kPag (operating)	4.21 mm	279 MPa	150 MPa
681 kPag (test)	6.32 mm	419 MPa	

APPENDIX B

Finite element analysis of redesigned bottom and selection

The fabricated bottom was redesigned using FEA. Different plate thicknesses and different support beams were used in a trial and error process until the calculated stresses reduced to below the maximum allowable stress. The stresses were reduced to below 148 MPa under operating pressure. This calculated value is below the allowable 150 MPa design stress as specified in the design code. The calculated deflections reduced to 2.47 mm and 3.71 mm under operating and test pressures respectively as shown in Table B1.

Table B1. Calculated results form FEA.

Applied pressure	Calculated defection	Maximum calculated Von Mises stress	Maximum allowable design stress
454 kPag (operating)	2.47 mm	148 MPa	150 MPa
681 kPag (test)	3.71 mm	222 MPa	

Selection

It was found, during the process of deciding on how to repair the OFFB, which failed the third party inspection, that torispherical Dished Ends (DE) had a delivery of 6-8 weeks at the time. Additional to this, a further 5-6 weeks would have been required to install the new DE, fill it with concrete, let it set for 21 days under vacuum and then coat the inside of the vessel and the top of the concrete with a protective coating, at this stage the “top hat” and stone bed solution had not been chosen. It was decided that due to these problems and the long down time, that the OFFB should be redesigned. This process of redesigning, fabrication and installation of the RFFB took about 8 weeks.