A NEW MOUNTING DESIGN FOR STEAM DISTRIBUTOR PLATES IN FIRST STAGE DEHYDROGENERATOR MIXERS

Rogério José Marczak
Depto. Engenharia Mecânica – UFRGS – Rua Sarmento Leite 425 – Porto Alegre – RS – 90050-170
rato@mecanica.ufrgs.br

Ignácio Iturrioz
Depto. Engenharia Mecânica – UFRGS – Rua Sarmento Leite 425 – Porto Alegre – RS – 90050-170
ignacio@mecanica.ufrgs.br

Jun Sério Ono Fonseca
Depto. Engenharia Mecânica – UFRGS – Rua Sarmento Leite 425 – Porto Alegre – RS – 90050-170
jun @ ufrgs.br

Eduardo Lenz Cardoso
Depto. Engenharia Mecânica – Campus Universitário Prof. Adelino Marcante – Joinville – SC – 89223-100
eduardo_lenz@yahoo.com.br

Cláudio Correa Becker
Innova S.A. – Rod. Tabaí/Canoas – BR 386 Km 419 – Pólo Petroquímico – Triunfo – RS – 95853-000
ccorrea@pecom.com

Abstract. *This work addresses a simple solution for a type of failure commonly found in styrene monomer (SM) mixer designs. Most last generation of SM plants are designed to mix ethylbenzene and primary steam (EB/PS) and main steam (MS) with minimum residence time by using static mixer elements in the dehydrogenerator reactor just upstream the first stage catalyst bed. The EB/PS and MS distributors are mounted upstream of the static mixer. These distributors aim a even EB/PS and MS flow into the pre-mix section, but produce a higher main stream inlet temperatures. The failure commonly detected in mixers with this new design occurs with relatively low operation time, and are characterized by a severe deformation of the perforated plate in the MS distributor. This type of failure has been observed in configurations consisting of a thick distributor plate mounted on a thin cylindrical liner. Because of the plate behavior, the liner collapses, destructing the adjacent insulation as well. Many of the proposed solutions for the problem suggest the use of a new configuration that substitutes a perforated ellipsoidal or spherical head for the thick perforated plate. The objective of this work is to present a simpler solution for the problem. The kinematical mechanism responsible for the plate failure is identified and analyzed, and a different distributor plate assembly is proposed. The proposal eliminates the use of oddly-shaped plates, and is based on a mounting design that allows dilatational deformations without transferring the corresponding loads to the liner walls. Finite element simulations illustrate the reduction of primary stresses on the plate obtained with the revised design. The proposed design was manufactured and tested in a Brazilian SM plant, and has been working uninterruptedly for two years, attesting the efficiency of the solution.*

Keywords*: Styrene monomer plants, steam distributor plants, thermal stress, finite element analysis*

1. Introduction

Dehydrogenerator mixers are commonly used in styrene monomer (SM) processing plants. During the last years, problems associated with the mixer of the first stage reactor have been reported in some plants around the world. The interaction between temperature level and mechanical behavior is the main issue in these cases, and efficient designs are necessary to avoid local collapses and the high cost associated with this type of failure.

The main goal of the present work is to present a new mounting design for steam distributor plates used in first stage dehydrogenerator mixers. The present design is easier to manufacture than other proposals and was found to perform efficiently under high temperature loads. The modified design is compared to two others by finite element models, showing better overall stress level reduction than its counterparts. The new solution has been under uninterrupted operation for 24 months in a Brazilian SM plant, without showing any kind of mechanical failure.

In the next section a description of the problem is shown. Section 3 details the temperature $\times$ material properties data used by the finite element model, while in section 4 the results obtained for all the configurations tested are presented. Section 5 compares the designs in order to select the best solution.

2. Problem description

Common SM mixers are designed to mix the ethyl benzene and primary steam (EB/PS) and main steam (MS) as efficiently as possible. This is accomplished by the use of static mixers mounted in the dehydro reactor just upstream of the first stage dehydro catalyst bed. EB/PS and main steam distributors are placed upstream of the static mixer elements. These distributors are designed to introduce the EB/PS flow steam and the main steam flow evenly into the pre-mix section before the combined flow enters the static mixing elements.

In the present work, the relevant area of the dehydrogenerator is the lower reactor area, where the EB/PS is mixed with the MS. The problems reported have been confined to the lowest section of the mixing sump, specifically the MS distributor liner. The liner has been showing severe plastic deformation, resembling an hourglass shape. The thick perforated plate showed a significant deformation, leading to fractures along the internal insulation and consequent unwanted mix with materials at lower temperatures. Figure 2 shows the amount of damage found in the perforated plate during a maintenance stop.

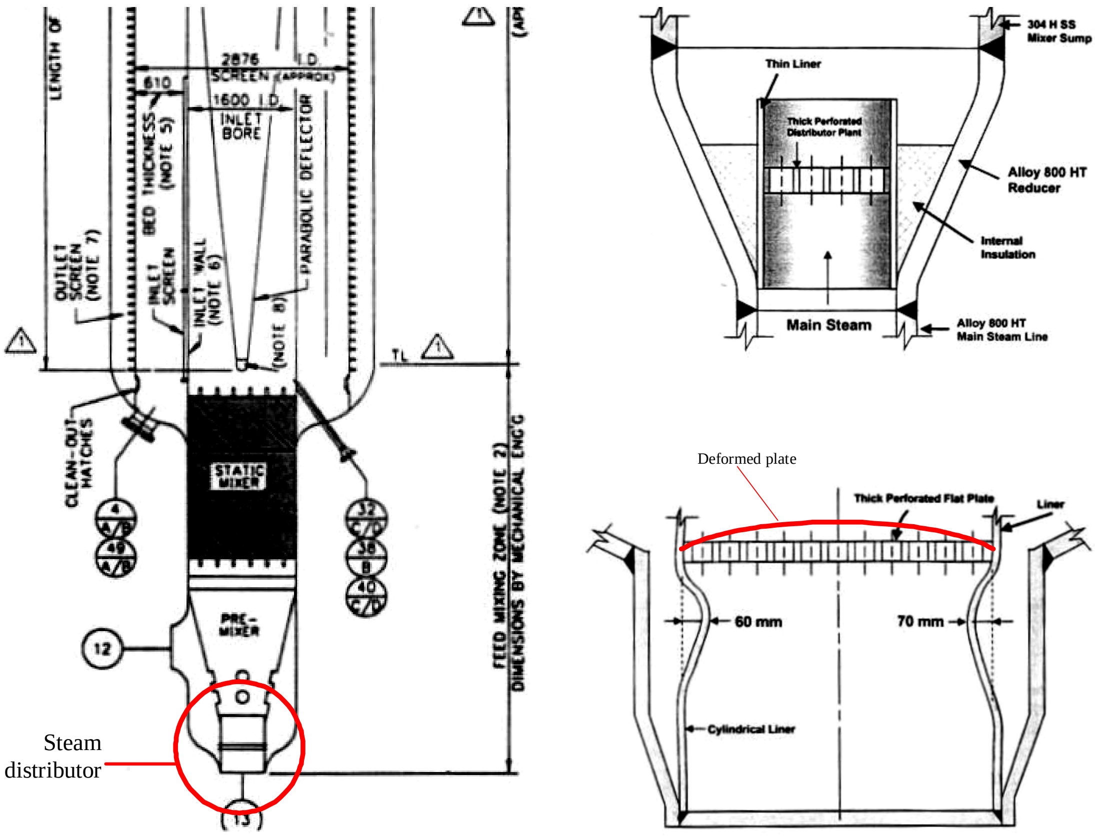


Figure 1. Localization of the MS liner and detail view of the failed components

Figure 2. (a) Aspect of the liner after failure. (b) Deformed perforated plate

3. Material data

The liner and the perforated plate are manufactured in 800HT steel. It is important to note that the remaining of the structure is manufactured in 304H stainless steel, so that a differential dilatation is expected around the reducer region (fig. 1). Figure 3 presents the relevant properties employed in this work as a function of the temperature.

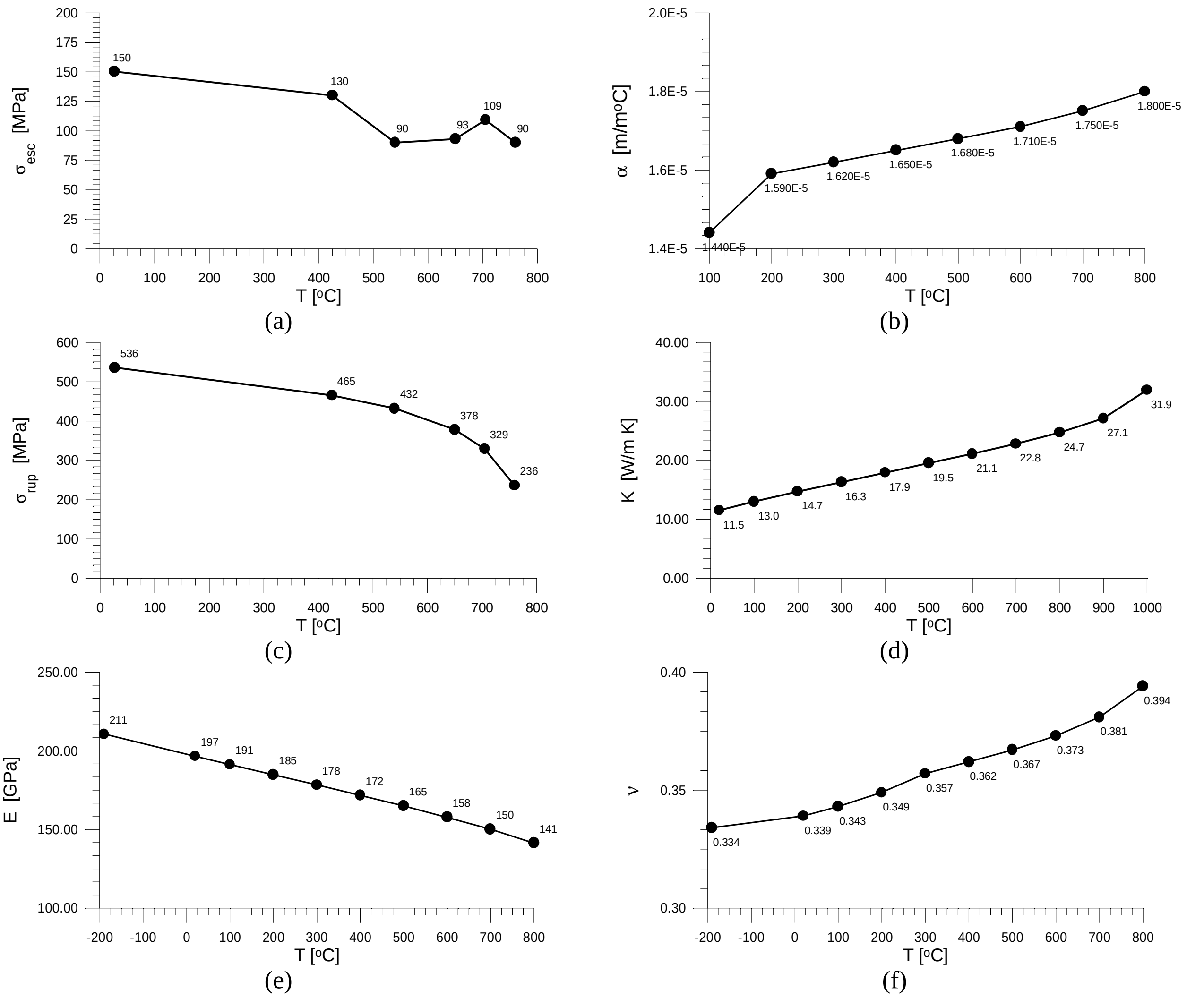


Figure 3. Relevant 800HT steel properties as a function of temperature: (a) Yield stress. (b) Ultimate stress. (c) Thermal expansion. (d) Thermal conductivity. (e) Young modulus. (f) Poisson modulus.

4. Numerical model

The numerical simulation was performed by finite element models. Regarding the symmetry of the structure, an axisymmetric analysis was employed, along with shell finite elements under commercial software.

Three designs were analyzed. The first one is the original distributor design, to be used as a comparison reference to the other proposals (fig. 4a – design D1). The second is a typical modification proposed by reactor manufacturers, based on an elliptical-shaped perforated head (fig. 4b – design D2). The third one is the design proposed herein (fig. 4c – design D3). It is clear that the proposal of fig. 4b aims the absorption of the liner dilatation through a more flexible perforated plate. The design D3 includes a radial gap intended to accommodate the plate's thermal deformations with a much simpler design. In this way, the plane plate can still be used, avoiding further over-engineering and simplifying the manufacturing. While the design D2 was a manufacturer recommendation, the design D3 was developed by the authors after initial finite element analyses and a careful interpretation of the corresponding deformation mechanism.

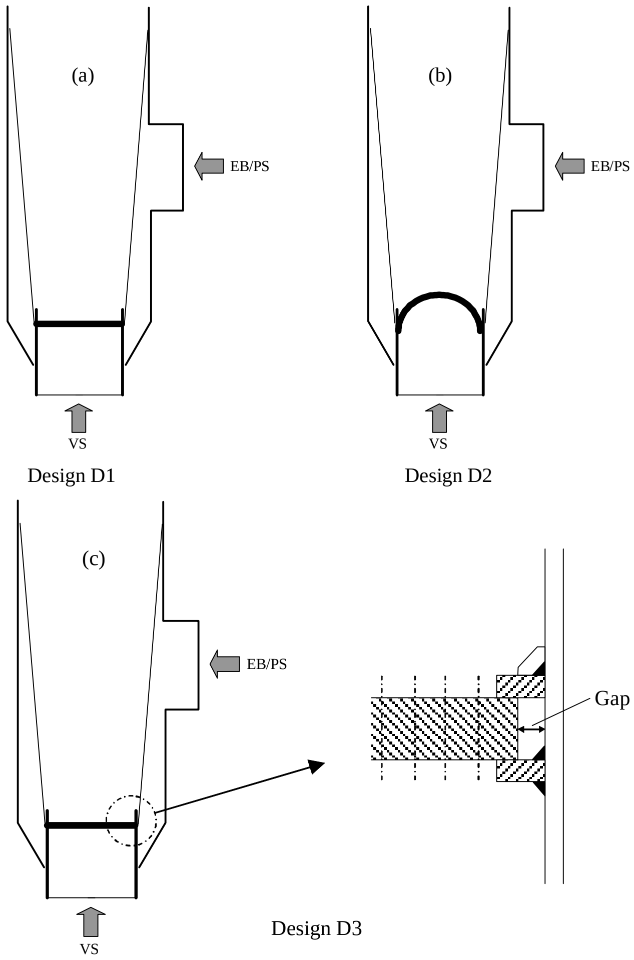


Figure 4. Designs analyzed: (a) Original design. (b) Modified proposal with elliptical perforated plate. (c) Modified proposal allowing dilatation of the perforated plate

4.1. Boundary conditions

According to the operational conditions (steady state), three sets of boundary conditions were imposed to the numerical models. Since only the relevant areas were modeled, displacement boundary conditions were imposed on the upper area of the vessel, as shown in fig. 5. On the lower ring, a distributed force was applied using the values measured by force transducers installed *in situ*.

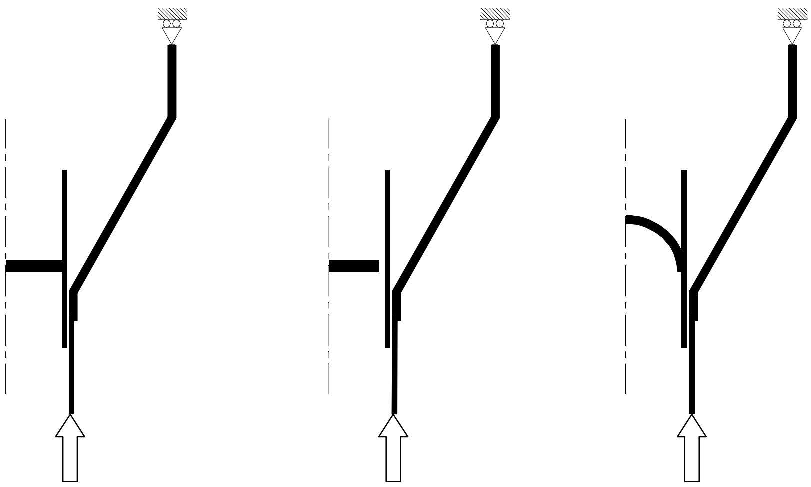


Figure 5. Force and displacement boundary conditions for the three designs analyzed

The second set of boundary conditions accounts for the temperature distribution along the various components of the reactor. These values were extracted directly from thermocouples installed on the equipment for maintenance purposes. Because the data acquisition was performed many months before the failure, these values resemble actual operational conditions. Figure 6 shows the temperature field used in the finite element computations. It is interesting to note the high temperature value achieved in some 800HT/304H steel transition areas.

The final set of boundary conditions refers to the pressure distribution inside the reactor. Again, actual values measured directly on the equipment during normal operation were used. These values are illustrated in fig. 7. Eventually the pressure boundary conditions showed marginal influence on the results.

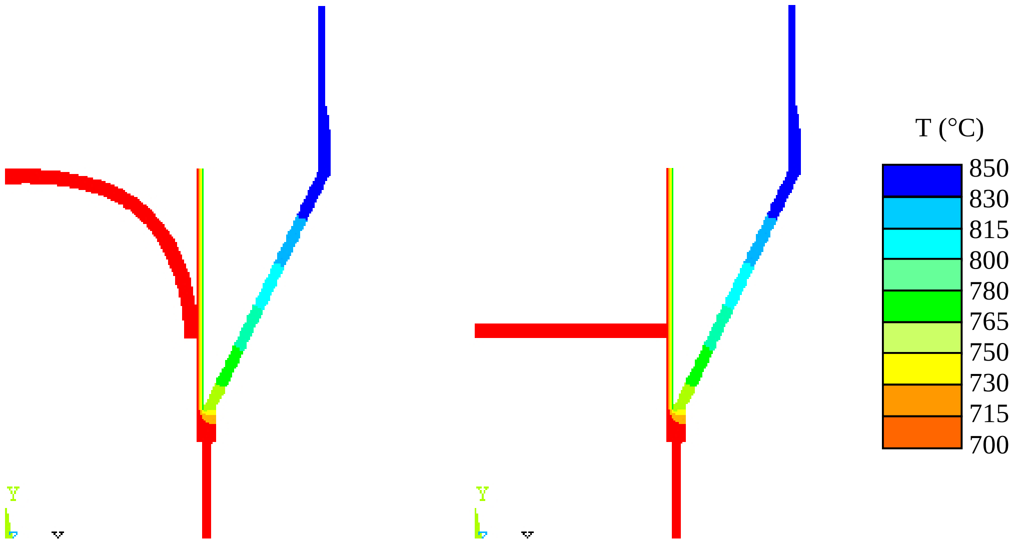


Figure 6. Temperature boundary conditions for the designs D2 (left) and D1 and D3 (right)

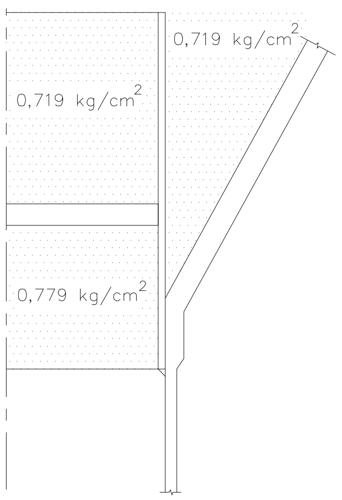
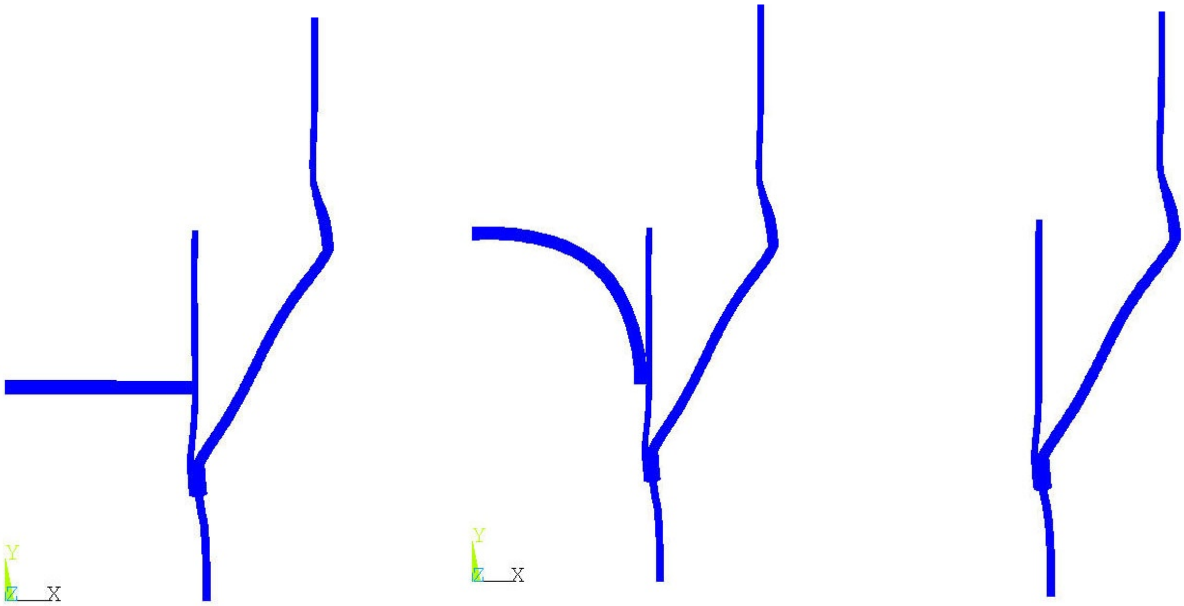


Figure 7: Pressure boundary conditions for all three designs analyzed.

5. Discussion

The finite element analysis allowed a direct comparison of the flexibility between the three designs. By comparing the deformation mechanisms (fig. 8), it was possible to verify that the design D2 does not absorb much of the deformation, as expected. In that design, the thermal stresses on the perforated plate resulted significantly lower than the original one (D1), but the amount of shear and moment forces transmitted to the liner were still too high. The proposal D3, on the other hand, allowed the expansion of the perforated plate without overloading the liner. The deformation around the 800HT/304H transition areas remained significant, though, and this was eventually remedied by the installation of external heat shields to distribute the temperature more evenly on the region.

In order to compare the stress distribution along the liner cylinder, eight stations were used to measure the equivalent stress (σ_{eq}) along both the internal and the external surfaces (fig. 9). These stress distributions are illustrated in figures 10 and 11, for internal and external surfaces, respectively.



(a) (b) (c)

Figure 8. Deformation pattern for the analyzed designs: (a) D1, (b) D2, (c) D3

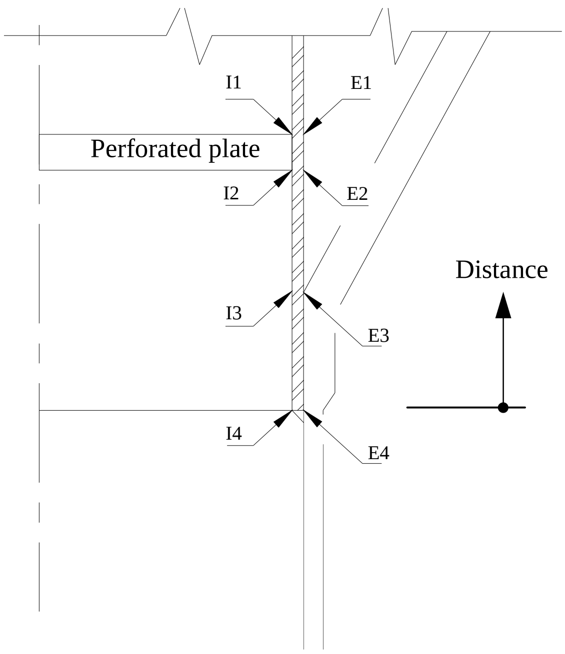


Figure 9: Stations used to verify the equivalent stress along the liner

From figs.10-11, it is clear that the proposed design D3 attains the best overall performance in what concerns the stress distribution. The design is particularly successful in avoiding the moment/shear transmission to the liner wall, and results a drastic reduction in the stress level where the perforated plate was originally welded. The stress peaks remain below 250 MPa along all the liner wall, in contrast to the designs D1 and D2 which showed peaks as high as 350-400 MPa.

Table 1 presents a comparison between the designs analyzed. Proposal D2 achieved stress reduction of 35% on station E2 when compared to the original design (D1), while the proposal D3 attained 79% and 70% stress reduction on stations E1 and E2, respectively.

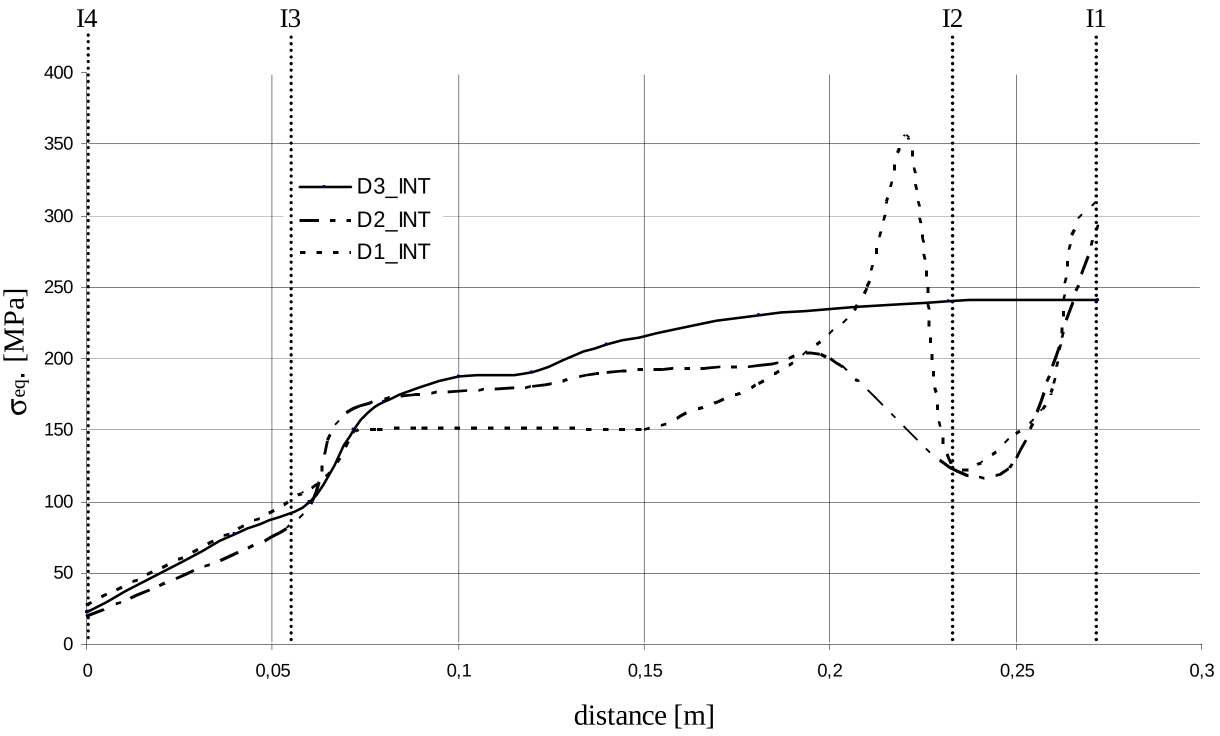


Figure 10: Equivalent stress along the internal surface of the liner

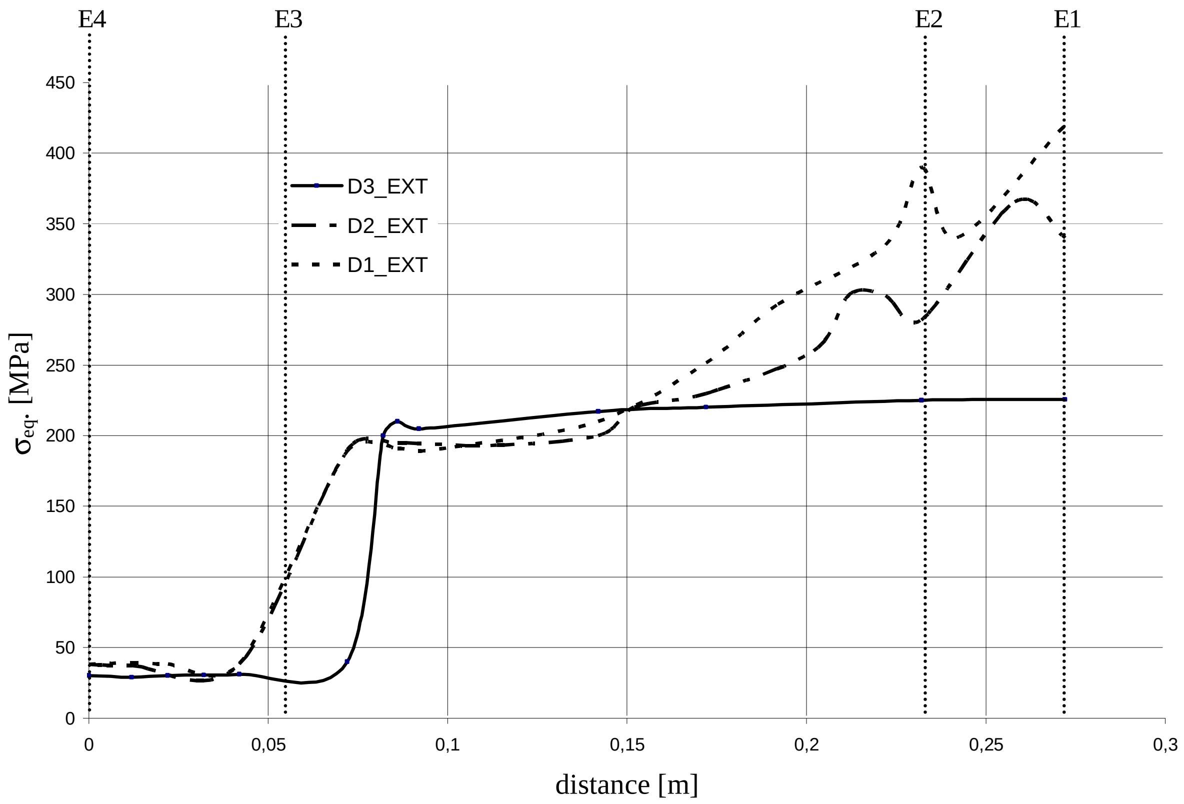


Figure 11: Equivalent stress along the external surface of the liner

Table 1. Result for σ_{eq} (in MPa) along stations 1 and 2. The values in parenthesis indicated the attained percent reduction/increase in σ_{eq} in comparison to the original design (D1).

	Design D1	Design D2	Design D3
Estation E1	420	350 (↓ 20%)	235 (↓ 79%)
Estation E2	390	290 (↓ 35%)	230 (↓ 70%)
Estation I1	310	295 (↓ 5%)	225 (↓ 38%)
Estation I2	130	125 (↓ 4%)	225 (↑ 58%)
Maximum	420	350	235

6. Conclusions

This work describes a failure commonly found in steam distributor plates used in first stage dehydrogenerator mixers of SM plants, and proposes a solution. Most reactor manufacturers have been instructing SM plants engineering staffs to install an ellipsoidal perforated heads to remedy the problem. The present results show that while this solution alleviates the stress on the plate, it does not avoid the high stress levels on the supporting liner. The investigation of the failure mechanism in these high temperature devices showed that the severe deformation of the plate is transferred to the liner wall, eventually leading to the collapse of the component. The design proposed in this work employs a plane plate, as in the original design, mounted on the liner in such a way that the dilatational deformations are not supported by the liner. A drastic stress level reduction was obtained, showing the efficiency of the solution. Assembly and manufacturing remained cheap and simple as in the original design. This proposal was manufactured and has been tested in a Brazilian SM plant, working uninterruptedly for two years. Considering the very high costs of dehydrogenerators, it is expected that the proposed design can be used in cases with similar failures and lead to improved designs in the future.

7. References

ABB Lummus Global Inc.,1997, Process Vessel Sketch, vessel no. 23-R-01 (DC-301).

ASM, 1961, Metals Handbook, vol. 1: *Properties and Selection of Metals*, Metals Park, Ohio.

ASME Pressure Vessel Code, Part VIII, Divisions 1 and 2, 1995.

Boller C. and Seeger, T., 1987, *Materials Data for Cyclic Loading – Part A: Unalloyed Steels*, Elsevier Science.

Boresi, A.P., Sidebotton, O.M., Selly F.B. and Smith, J.O., 1993, *Advanced Mechanics of Materials*, John Willey.

Cardoso, E.L., Iturrioz, I., Fonseca J.S.O. and Marczak, R.J., 2003, *Thermoelastic Analysis of the First Stage Dehydrogenerator Reactor – Partial Report* (in Portuguese), Internal Report 01-2003, GMAp – Grupo de Mecânica Aplicada, Departamento de Engenharia Mecânica, UFRGS.

Cardoso, E.L., Iturrioz, I., Fonseca J.S.O. and Marczak, R.J., 2003, *Thermoelastic Analysis of the First Stage Dehydrogenerator Reactor – Final Report* (in Portuguese), Internal Report 02-2003, GMAp – Grupo de Mecânica Aplicada, Departamento de Engenharia Mecânica, UFRGS.

Cervenka, J., Chaky, P., Johnson, T., van den Berg, R. and Weiner P., 2000, *First Stage Dehydrogenator Mixer Update*, Styrene Conference, Louisville, USA.

Chen, W.F. and Han, D.J., 1988, *Plasticity for Structural Engineers*, Springer-Verlag.

Chuse, R. and Carson, B.E., 1995, *Pressure Vessels - the ASME Code Simplified*, McGraw-Hill.

Hertzberg, R.W., 1996, *Deformation and Fracture Mechanics of Engineering Materials*, John Wiley.

Incoloy Alloys 800, 800H and 801; Huntington Alloys, Inc., 1978.

Nakoneczny, G.J. and Schultz, C.C., 1995, *Life Assessment of High Temperature Headers*, American Power Conference, Chicago, USA.

MATWEB's database. http://www.matweb.com/

8. Responsibility notice

The authors are the only responsible for the printed material included in this paper.