# Summary

# "Comparative Study on Pressure Equipment Standards"

European Commission, DG Enterprise, Contract N° FIF.20030114

Contractors: TÜV Austria (Austria), CEC (Italy)

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## 1. Introduction

Starting from May 30th, 2002, the European Union Pressure Equipment Directive (PED, 97/23/EC) is mandatory throughout the EU, thereby replacing existing national legislation in this area.
A reference, but not mandatory, way of demonstrating conformity to the Essential Safety Requirements of the PED is to use the new European harmonised standard EN 13445 (Unfired Pressure Vessels). This was prepared by CEN TC54 and was cited in the EC Official Journal in 2002.

In industry it is recognised that the harmonised standard related to a new approach directive does give the manufacturer the advantage of the presumption of conformity to the Essential Safety Requirements of the directive itself, but to be accepted and applied, it must also bring economic and/or technical advantages.

This study compares the economic and non-economic implications arising from the application of (a) EN 13445[1] and, (b) the ASME Boiler & Pressure Vessel Code[2] plus major related codes when appropriate (TEMA[3], WRC Bulletins[4]), for the design, manufacture, inspection and acceptance testing of 9 benchmark examples of unfired pressure vessels.

The consortium which carried out the study consisted of TUV Austria (the Pressure Equipment Division of which is a Notified Body appointed by the Austrian Government for the certification of pressure equipment in accordance with the PED), and of Consorzio Europeo di Certificazione (CEC), which likewise is a Notified Body appointed by the Italian Government in accordance with the PED.

The detailed design of the benchmark examples was performed by the consortium. To evaluate the economic factors concerning individual and/or serial production of the benchmark vessels, pressure equipment manufacturers from Italy, France, Germany and Austria took part as subcontractors.

## 2. Overview of the Pressure Vessel Example Cases

The following table summarises the 9 benchmark examples and gives an overview of the code routes applied (the choice of the code routes is mainly based on common industrial practice), and the materials for the main parts of the vessels. For the EN route the materials to be used were specified, while for the ASME route particular grades – adequate for the service conditions and comparable to the ones used for the EN route – were chosen.

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[1] EN 13445 Issue 1 (2002-05), including all correction pages issued by CEN before 2003-07, cited in OJ C171 of 2002-07-17

[2] 2001 ASME Boiler & Pressure Vessel Code (B&PV), including 2002 Addenda and 2003 Addenda

[3] 8th Edition of the Standards of the Tubular Exchanger Manufacturers Association, Inc., 1999

[4] WRC Bulletin 107 / Revision 1979; WRC Bulletin 297 / Revision1987; WRC Bulletin 368 / 1991.

| Ex. No. | Example Description | Code Routes applied[1] | Notes |
|---|---|---|---|
| 1 | CNG storage tank: Diameter 2200 mm, length app. 20000 mm, max. allowable pressure 70 bar, ambient temperature, material specified: fine-grained carbon steel.<br>Material used for EN: P460NH / EN10028-3 (shell and ends).<br>Material used for ASME: SA-738 Gr. B (shell and ends). | DBF according to EN 13445, ASME VIII Div. 1, ASME VIII Div. 2;<br>DBA according to EN 13445, ASME VIII Div. 2. | DBA according to ASME VIII Div. 2 does not lead to more economical results, and, thus, no results are given. |
| 2 | Hydrogen reactor with external piping loads: diameter 2200 mm, cylindrical length app. 8000 mm, hemispherical ends, max. allowable pressure 180 bar, max. allowable temperature 400°C, material 10CrMo9 10 (or similar).<br>The main shell may be fabricated with welded or forged courses, both methods are considered.<br>Material used for EN (forged courses): 11CrMo9 10 / EN 10222-2.<br>Material used for EN (welded courses): 12CrMo9 10 / EN 10028-2.<br>Material used for ASME (forged courses): SA-387 Gr.22 Cl.2.<br>Material used for ASME (welded courses): SA-336 Gr. F22 Cl.2. | DBF according to EN 13445, ASME VIII Div. 1, ASME VIII Div. 2;<br>DBA according to EN 13445, ASME VIII Div. 2 for the upper end. | DBA according to EN 13445 and according to ASME VIII Div. 2 do not lead to more economical results, and, thus, no results are given. |
| 3 | Jacketed autoclave, serially produced: diameter 500 mm, cylindrical length 800 mm, max. allowable pressure 2.5 bar, steam saturation temperature, material X5CrNi18 10 (or similar).<br>Material used for EN: X5CrNi 18 10 / EN 10028-7 (shell and flat end).<br>Material used for ASME: SA-240 Gr. TP304 (shell and flat end). | DBF according to EN 13445, ASME VIII Div. 1. | Fatigue analysis according to specified cyclic service mandatory. |
| 4 | Stirring vessel: diameter 3200 mm, cylindrical length app. 3500 mm, max./min. allowable pressure 3/-1 bar for the inner chamber, max. allowable pressure 3 bar for the jacket, max. allowable temperature 50°C, material X6CrNiMoTi17 12 2 (or similar).<br>Material used for EN: X6CrNiTi17 12 2 / EN 10028-7 (shells and ends).<br>Material used for ASME: SA-240 Gr. 316Ti (shell and ends). | DBF according to EN 13445, ASME VIII Div. 1, ASME VIII Div. 2. | Fatigue analysis according to specified cyclic stirrer loads mandatory.<br>DBF according to ASME VIII Div. 2 not performed since material SA-240 Gr. 316Ti is not allowed for this route. |
| 5 | Standard refinery heat exchanger, TEMA type AES: (inside) diameter 1062 mm, tube length 5888 mm, max. allowable pressures: shell side 10 bar, tube side 20 bar, calculation temperature 200°C (both sides), material: carbon steel.<br>Materials used for EN: P295GH / EN10028-2 (plates), P305GH / EN 10222-2 (forgings).<br>Materials used for ASME: SA-516 Gr. 70 (plates), SA-266 Gr. 2 (forgings). | DBF according to EN 13445 + TEMA, ASME VIII Div. 1 + TEMA. | |
| 6 | Standard refinery heat exchanger, TEMA type BEM: (inside) diameter 539 mm, tube length 6094 mm, max. allowable pressures: shell side 10 bar, tube side 20 bar, calculation temperature 200°C (both sides), material: carbon steel.<br>Materials used for EN: P295GH / EN10028-2 (plates), P305GH / EN 10222-2 (forgings).<br>Materials used for ASME: SA-516 Gr. 70 (plates), SA-266 Gr. 2 (forgings). | DBF according To EN 13445 + TEMA, ASME VIII Div. 1 + TEMA. | |

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[1] The abbreviations used within this context are DBF for Design-by-Formula, i.e. calculation of the required wall thicknesses by usage of formulas given in the relevant code, and DBA for Design-by-Analysis, i.e. calculation of the required wall thicknesses by use of the finite-element-method to calculate the stresses. Normally, DBA is applied on certain parts of vessels if the result is likely to be more economic than that resulting from DBF, or if no design formulas exist for the specific parts or loads under consideration, or if it is specially required, e.g. for safety reasons.

| | | | |
|---|---|---|---|
| 7 | Heat exchanger, TEMA Type NEN[1], serially produced: (inside) diameter 292 mm, tube length 1500 mm, max. allowable pressures: shell side 6 bar, tube side 3 bar, calculation temperatures: shell side 180°C, tube side 150°C, material: X5CrNi18-10 (or similar).<br>Materials used for EN: X5CrNi18 10 / EN 10028-7 (plates), X5CrNi18 10 / EN 10222-5 (forgings).<br>Materials used for ASME: SA-240 Gr. TP204 (plates), SA-336 Gr. F304LS (forgings). | DBF according to EN 13445 + TEMA, ASME VIII Div. 1 + TEMA. | Fatigue analysis mandatory. |
| 8 | Water separator with piping reactions, serially produced: (outer) diameter 406.4 mm, overall length app. 1100 mm, max. allowable pressure 34 bar, max. allowable temperature 240°C, material: carbon steel.<br>Materials used for EN: P265GH / EN 10216-2 (cylindrical shell), P265GH / EN 10028-2 (ends).<br>Materials used for ASME: SA-106 Gr.B (cylindrical shell), SA-285 Gr. C (ends). | DBF according to EN 13445, ASME VIII Div. 1. | |
| 9 | Air cooler header of rectangular cross-section with nozzle loads: internal dimensions 255 mm x 190 mm, length 3096mm, max. allowable pressure 77 bar, max./min. design temperature 120°C / -25°C, material: fine-grained carbon steel.<br>Material used for EN: P355NL1 / EN 10028-3 (flat parts).<br>Material used for ASME: SA-738 Gr. B (flat parts). | DBF according to EN 13445, ASME VIII Div. 1, ASME VIII Div. 2;<br>DBA according to EN 13445, ASME VIII Div. 2 | Application of ASME VIII Div. 2 is not allowed due to the required corner joint geometry. |

In cases where no detailed design methods are given in EN 13445, generally recognised engineering design approaches were used (e.g. for nozzle loads in vessels with rectangular cross-section - see Example 9) within the general philosophy of EN 13445 and in a form considered to be acceptable to the European notified bodies involved in the study when performing a design examination.

Following usual practice, the ASME approach has not been applied in cases where design details are not given in the relevant ASME code. Nevertheless, in Example 9 an approach similar to that used for EN 13445 for nozzle loads in a vessel with rectangular cross section was applied.

In cases when fatigue assessment was required for vessels being designed according to ASME VIII Div. 1, the fatigue approach given in ASME VIII Div. 2 was used.

In Annex 2 indicative drawings of the considered pressure vessel example cases are given.

## 3. Conformity Assessment Routes

For estimation of the costs the following combinations of codes and conformity assessment routes were considered:

- EN 13445 and conformity assessment according to the PED (CE-marking).
- ASME Section VIII (Division 1, Division 2 if applied) and conformity assessment according to ASME (U-stamp, or U2-stamp), presuming that the manufacturers already held these stamps and were entitled to use them.
- ASME Section VIII (Division 1, Division 2 if applied) and conformity assessment according to the PED (CE-marking).

The exercise was based on compliance with the corresponding requirements assuming no pre-existing qualifications or supplementary data from other similar equipment.

In the case of application of the ASME Section VIII + PED route the following additional requirements were made. These were based on an agreement between the members of the consortium on the general approach taken within their organisations to such matters, and cannot be taken as generally valid for PED conformity assessment for vessels designed according to the ASME code.

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[1] In TEMA nomenclature AES; BEM and NEN, the first letter designates the front end stationary head, the second letter is the shell type (one pass shell in each case here) and the third letter is the rear end head type.

Materials:

- The material properties used in the design must be based on those affirmed by the material manufacturer (see also guideline 7/24 to the PED). This can include hot tensile properties for materials as given in ASME II Table Y-1 (yield strength values) and impact properties for carbon steels at MDMT[1] but not higher than 20°C, with a minimum value of 27 J according to the PED, Annex I, section 7.5. Note: Since the minimum required impact properties for carbon steel also apply to the weld and the HAZ[2], these shall be shown in the welding procedure approval. The requirements apply also for material properties after forming or post weld heat treatment, and, thus, also these properties must be affirmed.

Test pressure requirements are as follows:

- The requirement given in the PED, Annex I clause 7.4, that the hydraulic test pressure $P_{test}$ shall not be smaller than 1.43 PS shall be adhered to even if this requires an increase in wall thickness when an "equivalent design pressure $P_{eq}$" given by $P_{eq} = P_{test} \times S/S_a/1{,}3$ is greater than PS. In this context PS is the maximum allowable working pressure, S is the nominal design stress (allowable stress) for normal operating load cases at maximum design temperature and $S_a$ is the nominal design stress (allowable stress) for normal operating load cases at test temperature.
- The second requirement (1.25 times PS times the correction factor based on the proof strengths of ASME II-D Table Y-1) shall not be used when the resulting test pressure would be greater than the test pressure specified by the ASME Code ($1{,}3 \times S_a/S \times PS$).
- In this latter case the NDT level should be at least that corresponding to a joint efficiency of 0.85, even when a smaller efficiency is permitted by ASME.

Fatigue Design:

- Fatigue design according to ASME Div. VIII Sec. 2 Appendix 5 for welded regions is considered to be non-conservative in comparison with procedures in major European pressure vessel codes (e.g. EN 13445, AD-Merkblatt[3], PD 5500[4]) and the underlying experimental results. Thus, ASME fatigue design for these regions is not considered to meet the requirements of PED Annex I. Taking this into account, the results of alternative design procedures may be required for fatigue evaluation, i.e. re-assessment of the fatigue life using a European approach would be desirable in practice, but was not performed within this study. However for the purposes of the comparisons made in this project, the costings for the ASME designs involving fatigue do not include extra charges in this respect.

For permanent joining and NDT, the requirements of the PED must be fulfilled, i.e.

- For pressure equipment in categories II, III and IV, welding operating procedures and personnel must be approved by a competent third party (notified body or third party organisation recognized by a member state). To carry out these approvals the third party must perform examinations and tests as set out in the appropriate harmonised standards or equivalent examinations and tests or must have them performed.
- For pressure equipment in categories III and IV, the NDT personnel must be approved by a third party organisation recognised by a member state.

## 4. Technical and Economical Results for Each Example

For each of the 9 vessel example cases the consortium performed detailed design calculations according to the requirements explained in the preceding sections. These were then sent to the participating manufacturers, who provided overall costings for each design/conformity assessment route combination. The overall results of the exercise are contained in the project final report[5]. The following provides a summary of the findings concerning the technical issues and the costing evaluations. The results of the

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[1] Minimum Design Metal Temperature according to ASME B&PVC

[2] Heat Affected Zone

[3] AD 2000 Regelwerk, October 2003, Carl Heymanns Verlag

[4] PD 5500: 2003, Specification for Unfired Fusion Welded Pressure Vessels, BSI

[5] Comparative Study on Pressure Equipment Stabdards, Service Contract FIF.20030114,Final Report, June 2004, European Commission, Enterprise Directorate – General.

costing evaluations are given in relative terms only, on a percentage basis using as reference the total cost for the EN 13445 (using DBF) route quoted by the manufacturers. It is noted that expressed in absolute numbers, 100% EN costs quoted by manufacturer A usually differ from 100% EN costs quoted by manufacturer B. The costs for different tasks (design, materials and material testing, fabrication, testing, conformity assessment) could not be compared reliably since different manufacturers attributed the costs for different tasks according to different criteria, but the total costs of the vessels can be assumed to be those used for the overall offer. Costs for the ASME stamp or costs for a quality assurance system according to the PED were not included in the cost evaluations.

In the following, the results summary is given on a per example basis. Together with the indicative drawings, Annex 2 includes a "comparison of results sheet" for each example, which lists the used materials and the wall thicknesses resulting from the design calculations and some important notes on the design.

Example 1 – CNG Storage Tank:

Differences in the design wall thicknesses (e.g. for the main cylindrical shell 34mm for EN 13445 DBF, 28.5 mm for EN 13445 DBA, 47.5 mm for ASME VIII Div.1, and 40 mm for ASME VIII Div. 2) are mainly caused by the different allowable stresses. This affects also the requirements for post weld heat treatment, which is necessary for the ASME designs (because of the resulting wall thicknesses) but not for the EN designs.

The following table gives an overview of the relative costs quoted by the manufacturers:

| Manufacturer | EN 13445 DBF | EN 13445 DBA | ASME VIII Div 1 | ASME VIII Div 1 + PED | ASME VIII Div. 2 | ASME VIII Div. 2 + PED |
|---|---|---|---|---|---|---|
| A | 100,0 % | 92,5 % | 156,9 % | 166,3 % | 138,5 % | 137,6% |
| B | 100,0 % | 99,3 % | 116,8 % | 125,7 % | 108,9 % | 109,7 % |
| C | 100,0 % | 95,0 % | 117,5 % | 123,7 % | 106,9 % | 106,5 % |

The cost differences for the different routes from different manufacturers compared with those for EN 13445 DBF (estimated for one-off production) are:

| | |
|---|---|
| EN 13445 DBA | –0.7 % to –7.5 % |
| ASME VIII Div. 1 | +16.8 % to +56.9 % |
| ASME VIII Div. 2 | +6.9 % to +38.5 % |

One can conclude that DBA according to EN 13445-3 Annex B is advantageous in this case and that the higher design costs due to finite-element analysis are easily compensated (also due to the fact the analysis is rather simple in this case).

The higher costs for the ASME design are basically caused by higher material costs, due to larger wall thicknesses, and to some extent by the post weld heat treatment costs. A vessel according to ASME VIII Div.2 is considerably cheaper than one according to ASME VIII Div.1 due to the large differences in the resulting wall thicknesses.

The NDT (Non Destructive Testing) requirements according to EN 13445 for the welds of the main body of the vessel are the same as according to ASME VIII Div. 1. For other welds the requirements according to ASME VIII Div. 1 (spot or no NDT) are less than the ones according to EN (full NDT). The NDT requirements according to ASME VIII Div. 2 are similar to those according to EN. Thus, the NDT requirements should not result in considerable cost differences.

Test coupons (production test plates) are required for the EN design routes, but not for ASME design, which results in higher costs for EN for this task.

The additional costs for the ASME vessels if conformity assessment with the PED is required are rather small (some marginally increased wall thicknesses for ASME VIII Div.1, higher testing requirements for the materials) – presuming that the results of the material tests fulfil the requirements. In the case of ASME VIII Div. 2, no increase of the wall thicknesses due to the hydraulic test pressure given by the PED is required.

Example 2 – Hydrogen Reactor:

Since discussions with manufacturers showed that some of them would manufacture the hydrogen reactor using forged courses while others would use welded courses, both routes are considered – especially since the corresponding design results differ considerably. It must be stated that there is no noticeable technical difference between the two solutions, but the usage of forged or welded courses may depend on the manufacturing equipment of the manufacturer and on the availability of the materials on the market, because forgings may be difficult to obtain quickly.

Design of the upper end by applying Design-by-Analysis according to EN 13445-3 Annex B for consideration of the nozzle loads does not result in decreased thicknesses compared to those obtained by DBF. Thus, no results are given for this route.

Since design according to ASME VIII Div. 2 Appendix 4 (design based on stress analysis) does not lead to decreased wall thicknesses for some of the main parts (e.g. cylindrical shells under internal pressure) in comparison to those obtained by the design formulae in ASME VIII Div. 2, no details are given for such a route.

Differences in the design wall thicknesses (e.g. for the main cylindrical shell / forged courses 190 mm for EN 13445 DBF, 181 mm for ASME VIII Div.1, and 151 mm for ASME VIII Div. 2; and for the main cylindrical shell / welded courses 124 mm for EN 13445 DBF, 181 mm for ASME VIII Div.1, and 151 mm for ASME VIII Div. 2) are mainly caused by the different allowable stresses.

In the case of the EN approach the material properties which are the basis for the design differ considerable for the forged material 11CrMo9-10 according to EN 10222-2 and the plate material 12CrMo9-10 according to EN 10028-3. Thus, the resulting wall thicknesses of the cylindrical main body for the EN DBF approach differ considerable: 190 mm for the forged material and 124 mm for the plate material.

The following table gives an overview of the relative costs quoted by the manufacturers:

| Manufacturer / course type | EN 13445 DBF | ASME VIII Div 1 | ASME VIII Div 1 + PED | ASME VIII Div. 2 | ASME VIII Div. 2 + PED |
|---|---|---|---|---|---|
| A / forged | 100,0 % | 93,3 % | 93,3 % | 86,6 % | 86,6% |
| B / forged | 100,0 % | 95,9 % | 97,5 % | 88,2 % | 89,4 % |
| C / forged | 100,0 % | 93,8 % | 93,8 % | 79,9 % | 79,9 % |
| A / welded | 100,0 % | 112,2 % | - | - | - |
| B / welded | 100,0 % | - | - | 105,5 % | 106,9 % |
| C / welded | 100,0 % | 119,6 % | 122,8 % | 107,5 % | 114,2 % |

The cost differences for the different routes from different manufacturers compared with those for EN 13445 DBF (estimated for one-off production) are:

Forged courses:

| | |
|---|---|
| ASME VIII Div. 1 | -4.1 % to -6.7 % |
| ASME VIII Div. 2 | -11.8 % to -20.1 % |

Welded courses:

| | |
|---|---|
| ASME VIII Div. 1 | +12.2 % to +19.6 % |
| ASME VIII Div. 2 | + 6.9 % to +14.2 % |

The higher costs for EN design for forged courses are basically caused by higher material costs, higher fabrication costs and to some extent by the post weld heat treatment costs. The higher costs for ASME design for welded courses are also basically caused by higher material costs, higher fabrication costs and to some extent by the post weld heat treatment costs. A vessel according to ASME VIII Div.2 is considerably cheaper than one according to ASME VIII Div.1 due to the large differences in resulting wall thicknesses.

The additional costs for the ASME vessels if conformity assessment with the PED is required are rather small (some marginally increased wall thicknesses for ASME VIII Div.1, higher testing requirements for the materials) – presuming that the results of the material tests fulfil the requirements. In the case of ASME VIII Div. 2, no increase of the wall thicknesses due to hydraulic test pressure given by the PED (see section 3 above) is required.

The NDT requirements according to EN and to ASME are (with one exception) identical, and test coupons are required for all the design routes considered.

Example 3 – Jacketed Autoclave:

The main technical issue to arise from this example concerns the fatigue evaluation, which includes cyclic thermal stresses. This was initially performed according to both EN 13445-3 clause 18, and ASME VIII Div. 2 Appendix 5. The results differ substantially: the allowable number of cycles according to EN is 33576, whereas that according to ASME is larger than $10^6$.

As discussed in section 3 above, the ASME fatigue design for welded regions is however not considered to meet the requirements of PED Annex I. Taking this into account, the results of alternative design procedures may be required for fatigue evaluation, i.e. re-assessment of the fatigue life using a European approach would be desirable in practice, but was not performed within this study. For the purposes of the comparisons made in this project, the costings for the ASME designs involving fatigue do not include extra charges in this respect.

It is also noted that in a strictly formal ASME Sec. VIII Div. 1 approach a bayonet closure is not allowed since no specific formulas are given for such a geometry.

The following table gives an overview of the relative costs quoted by the manufacturers:

| Manufacturer | EN 13445 DBF | ASME VIII Div 1 | ASME VIII Div 1 + PED |
|---|---|---|---|
| A | 100,0 % | 109,4 % | 109,4 % |
| B | 100,0 % | 92,6 % | 94,7 % |
| C | 100,0 % | 91,7 % | 91,7 % |

The differences in the wall thicknesses resulting from the designs according to EN 13445 and ASME VIII Div. 1 are low, and, thus, the resulting material and fabrication costs are similar.

The additional costs for the ASME vessels if PED conformity assessment is required are also rather small (some wall thicknesses marginally increased for ASME VIII Div.1, higher testing requirements for the materials) – presuming that the results of the material tests fulfil the requirements.

The NDT requirements are similar and no cost differences are caused by them.

The requirements for test coupons according to EN 13445 increase the costs for EN design, since no test coupons are required for ASME VIII Div.1.

The cost differences for the different routes from different manufacturers compared with those for EN 13445 DBF (estimated based on serial production of 10 vessels) are between –8,3 % and +9,4 %, depending on the manufacturer. Thus, it can be concluded that the two routes result on average in equal costs.

Example 4 – Stirring Vessel:

The mandatory fatigue assessment also proved to be a technical issue for this example case. The necessary analysis of the upper end was performed according to both EN 13445-3 clause 18, and according to ASME VIII Div. 2 Appendix 5. The fluctuating load components rotate about the stirrer axis and are assumed to act in the most unfavourable way. Design for an infinite number of cycles of the stirrer forces and moments was required. It is assumed, that the stirrer forces occur at a constant service pressure and thus the analysis is not affected by internal pressure fluctuations. According to EN 13445-3 clause 18 the design for an infinite number of stirrer action cycles must meet the requirements for $5 \cdot 10^6$ cycles. On the other hand, since no fatigue endurance limit is given in ASME VIII Div. 2 Appendix 5, the requirements for the maximum given cycle number in the code ($10^{11}$ for series 3XX high alloy steels) are used. A fatigue analysis for the upper end, leading to the allowable number of (specified) batch cycles, was also performed.

The results differ substantially: in particular the required reinforcement of the mounting flange to obtain stresses which result in a design for an infinite number of load cycles is different for the two code routes. Furthermore, the allowable number of batch cycles according to EN is 13100, but that according to ASME is $2 \times 10^8$.

As discussed in section 3 above, the ASME fatigue design for welded regions is however not considered to meet the requirements of PED Annex I. Taking this into account, the results of alternative design procedures may be required for fatigue evaluation, but was not performed within this study. For the purposes of the comparisons made in this project, the costings for the ASME designs involving fatigue do not include extra charges in this respect.

Application of the DBA route according to EN 13445-3, Annex B, for the upper end does not lead to any design advantages since the fatigue stresses govern the design (wall thicknesses). Thus, this method is not applied here.

Since the material SA-240 Grade 316Ti is not allowed for application of ASME VIII Div. 2, and the allowable stress of SA 240 Grade 316L is considerably lower, the application of ASME VIII Div. 2 would generally lead to larger wall thicknesses for the shells and ends. Thus, application of ASME VIII Div. 2 is not economic in this case.

For the cylindrical (inner) body of the vessel, the differences in the design wall thicknessess are mainly caused the different design methods for external pressure (EN design: 11 mm wall thickness, two reinforcing rings 25x125 mm; ASME design: 15 mm wall thickness, two reinforcing rings 30x160 mm). For the inner dished end the differences in the design wall thicknessess are also mainly caused by the different design methods for external pressure (EN design: 15 mm wall thickness; ASME design: 23 mm wall thickness). For the dished end of the jacket the differences in the design wall thicknessess are mainly caused by the different design formulas for internal pressure (EN design: 10 mm wall thickness; ASME design: 7 mm wall thickness).

The following table gives an overview of the relative costs quoted by the manufacturers:

| Manufacturer | EN 13445 DBF | ASME VIII Div 1 | ASME VIII Div 1 + PED |
|---|---|---|---|
| A | 100,0 % | 127,6 % | 125,9 % |
| B | 100,0 % | 100,6 % | 102,3 % |
| C | 100,0 % | 103,6 % | 103,8 % |

The cost differences for the different routes from different manufacturers compared with those for EN 13445 DBF (estimated for one-off production) are:

| | |
|---|---|
| ASME VIII Div. 1 | 0.6 % to 27.6 % |
| ASME VIII Div. 1 + PED | 2.3 % to 25.9 % |

The higher costs for the ASME designs are basically caused by higher material costs due to larger wall thicknesses, and thus higher fabrication costs. These are partly compensated by lower costs for NDT and for test coupons, since the NDT requirements according to ASME are lower than those according to EN (for the chosen weld joint efficiency) and due to the fact that no test coupons are required for the ASME route.

The additional costs for the ASME vessels if PED conformity assessment is required are rather small and are mainly caused by higher material costs due to the required increased wall thickness for the lower end and the costs for an additionally required pad at a nozzle. Due to the moderate service temperature no hot tensile test is required, and no additional impact testing is considered necessary for the austenitic steels used. Thus, the additional costs for material testing are negligible.

Example 5 – AES Heat Exchanger:

The minimum plate thickness is according to TEMA for both, the EN and ASME approaches and this tends to equalize the designs. The larger wall thicknesses for the flanges and the floating tubesheet resulting from the design according to ASME VIII Div. 1 in comparison to those according to EN 13445 lead to higher material costs for the ASME route according to one manufacturer, but not according to the other two.

The following table gives an overview of the relative costs quoted by the manufacturers:

| Manufacturer | EN 13445 DBF | ASME VIII Div 1 | ASME VIII Div 1 + PED |
|---|---|---|---|
| A | 100,0 % | 105,6 % | 106,6 % |
| B | 100,0 % | 94,1 % | 97,8 % |
| C | 100,0 % | 101,0 % | 101,0 % |

The additional costs for the ASME vessels if PED conformity assessment is required are also rather small (some marginally increased wall thicknesses for ASME VIII Div.1, higher testing requirements for the materials) – presuming that the results of the material tests fulfil the requirements.

The NDT requirements are similar and no cost differences are caused by them.

The requirements for test coupons according to EN 13445 increase the costs for EN design, since no coupons are required for ASME VIII Div.1.

The cost differences for the ASME VIII Div.1 route from different manufacturers compared with those for EN 13445 DBF (estimated for one-off production) are between –5,9% and +5,6%, depending on the manufacturer. Thus, it can be concluded that the two routes result on average in equal costs.

Example 6 – BEM Heat Exchanger:

The minimum plate thickness is according to TEMA for both EN and ASME approaches and this tends to equalize the designs. The larger wall thickness for the tubesheet from the design according to ASME VIII Div. 1 in comparison to those according to EN 13445 leads to higher material costs for the ASME route according to one manufacturer, but not according to the other two.

The following table gives an overview of the relative costs quoted by the manufacturers:

| Manufacturer | EN 13445 DBF | ASME VIII Div 1 | ASME VIII Div 1 + PED |
|---|---|---|---|
| A | 100,0 % | 106,0 % | 107,8 % |
| B | 100,0 % | 89,0 % | 95,8 % |
| C | 100,0 % | 102,0 % | 102,0 % |

The additional costs for the ASME vessels if PED conformity assessment is required are also rather small (higher testing requirements for the materials) – presuming that the results of the material tests fulfil the requirements.

The NDT requirements are similar, a cost difference (higher costs according to EN design) is reported by one manufacturer, but not by the other two.

The requirements for test coupons according to EN 13445 increase the costs for EN design, since no coupons are required for ASME VIII Div.1.

The cost for the ASME VIII Div.1 route from different manufacturers compared with those for EN 13445 DBF (estimated for one-off production) are between –11,0% and +6,0%, depending on the manufacturer. Therefore, it seems to depend on the manufacturer and material supplier as to which design route results in a cheaper vessel.

Example 7 – NEN Heat Exchanger:

Differences in the wall thickness for the tubesheet (11 mm for EN, 10 mm for ASME), the flange (26 mm for EN, 28 mm for ASME) and the cover (26 mm for EN, 28 mm for ASME) lead to higher material costs for the ASME route according to one manufacturer, but not according to the other.

The following table gives an overview of the relative costs quoted by the manufacturers:

| Manufacturer | EN 13445 DBF | ASME VIII Div 1 | ASME VIII Div 1 + PED |
|---|---|---|---|
| A | 100,0 % | 117,4 % | 117,4 % |
| B | 100,0 % | 99,0 % | 99,3 % |

The additional costs for the ASME vessels if PED conformity assessment is required are also rather small (hot tensile test requirement for the materials) – presuming that the results of the material tests fulfil the requirements.

RT/UT[1] examination is not required according to ASME, but according to EN 10% examination is required for all welds with one exception. The MT/PT[2] requirements for ASME are slightly higher than those for EN. Overall this results in higher NDT costs for the EN design.

The requirements for test coupons according to EN 13445 increase the costs for EN design, since no coupons are required for ASME VIII Div.1.

The cost differences for the ASME VIII Div.1 route from different manufacturers compared with those for EN 13445 DBF (estimated based on serial production of 10 vessels) are between –1,0% and +17,4%, depending on the manufacturer. Therefore, it seems to depend on the manufacturer and material supplier which design route results in a cheaper vessel.

Example 8 – Water Separator:

For the aspects of the design, it is noted that in this case the wall thickness of the main cylindrical shell is determined by the specified nozzle loads and not due to the internal pressure calculation.

The dimensions of the bracket supports are chosen according to DIN 28083 size 2, and the dimensions of the lifting lugs are chosen according to DIN 28086 size 1; this applies for both EN and ASME design.

Some difference was evident in the design wall thicknesses of the dished ends (EN: 9 mm, ASME: 13 mm), which is mainly caused by the different allowable stresses and design formulas.

The following table gives an overview of the relative costs quoted by the manufacturers:

| Manufacturer | EN 13445 DBF | ASME VIII Div 1 | ASME VIII Div 1 + PED |
|---|---|---|---|
| A | 100,0 % | 106,6 % | 115,6 % |
| B | 100,0 % | 104,6 % | 104,6 % |

The cost differences for the different routes from different manufacturers compared with those for EN 13445 DBF (estimated on serial production of 30 vessels) are:

| | |
|---|---|
| ASME VIII Div. 1 | 4.6 % to 6.6 % |
| ASME VIII Div. 1 + PED | 4.6 % to 15.6 % |

The higher costs for ASME design are basically caused by higher material costs due to larger wall thicknesses for the dished ends, and thus, higher fabrication costs. These are partly compensated by the lower costs for NDT, since the NDT requirements according to ASME are less onerous than those according to EN.

The additional costs for the ASME vessels if PED conformity assessment is required are – according to one manufacturer – considerable, and are mainly caused by additional material testing requirements.

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[1] Radiographic / Ultrasonic Testing

[2] Magnetic Particle / Pentretation Testing

Example 9 – Air Cooler:

Application of ASME VIII Div. 2 is not possible since the required corner joint weld geometry is not allowed within the rules of this code.

Formally, ASME VIII Div. 1 is not applicable since no guidance is given on the analysis of nozzle loads for the geometry considered. Usage of ASME VIII Div. 2 Appendix 4 would be a basic possibility, but, as stated above, the vessel cannot be built under these rules. Nevertheless, ASME VIII Div. 1 is applied and an approach similar to those used for EN 13445 for nozzle loads in a vessel with rectangular cross section was used. This design approach for the nozzle loads is considered to be acceptable within the general philosophy of EN 13445.

For the ASME route, the design of the weld joint details for the box header follows Appendix 28 of ASME VIII Div. 1.

The differences in the design wall thicknesses of the flat parts by usage of EN DBF and ASME are mainly caused by the different allowable stresses (tube plate, plug plate and side wall according to EN DBF 40 mm; tube plate and plug plate 46 mm and side wall 43 mm according to ASME). The detailed finite-element-analysis in the EN DBA route is advantageous in comparison with the other routes and gives considerably lower thicknesses (tube plate, plug plate and side wall 34 mm), for which no post weld heat treatment is required.

The following table gives an overview of the relative costs quoted by the manufacturer:

| Manufacturer | EN 13445 DBF | EN 13445 DBA | ASME VIII Div 1 | ASME VIII Div 1 + PED |
|---|---|---|---|---|
| A | 100,0 % | 88,1 | 106,7 % | 108,2 % |

The cost differences for the different routes compared with those for EN 13445 DBF (estimated for one-off production) are:

| | |
|---|---|
| EN 13445 DBA | –11.9 % |
| ASME VIII Div. 1 | +6.7 % |
| ASME VIII Div. 1 + PED | +8.2 % |

One can conclude that DBA according to EN 13445-3 Annex B is advantageous and that the higher design costs due to finite-element analysis are easily compensated by lower wall thicknesses and due to the fact that no post heat treatment is required.

The higher costs for ASME design are basically caused by higher material costs, and thus, higher fabrication costs.

The additional costs for the ASME vessels if PED conformity assessment is required are rather small (some marginally increased wall thicknesses for ASME VIII Div.1, higher testing requirements for the materials) – presuming that the results of the material tests fulfil the requirements.

The NDT requirements according to EN and ASME are similar and do not result in an appreciable cost difference.

## 5. Summary and Conclusions

a) The project has considered application of the new harmonised standard EN 13445 and the ASME VIII design procedures to a set of 9 example cases which covered a wide range of pressure vessel types, designs, materials and fabrications.

b) The overall basis for comparison was one of economic cost. A procedure was used which allowed fair comparison of three routes: EN 13445, ASME + U-stamp, ASME + PED. While the consortium performed the design, several EU manufacturers were involved in the project to assess the costs.

c) The following table summarizes the mean values of the relative costs, i.e. mean of the relative costs quoted by the different manufactures, for each vessel and code route considered:

| Example | EN 13445 DBF | EN 13445 DBA | ASME VIII Div. 1 | ASME VIII Div. 1 + PED | ASME VIII Div. 2 | ASME VIII Div. 2 + PED |
|---|---|---|---|---|---|---|
| (1) CNG storage tank | 100,0% | 95,6% | 130,4% | 138,5% | 118,1% | 117,9% |
| (2a) Hydrogen reactor (welded course) | 100,0% | No benefit | 115,9% | 122,8% | 106,5% | 110,5% |
| (2b) Hydrogen reactor (forged course) | 100,0% | No benefit | 94,3% | 94,9% | 84,9% | 85,3% |
| (3) Jacketed autoclave[1)] | 100,0% | Not required | 97,9% | 98,6% | Not required | Not required |
| (4) Stirring vessel[1)] | 100,0% | No benefit | 110,6% | 110,6% | Not applicable | Not applicable |
| (5) AES heat exchanger[2)] | 100,0% | Not required | 100,3% | 101,8% | Not required | Not required |
| (6) BEM heat exchanger[2)] | 100,0% | Not required | 99,0% | 101,9% | Not required | Not required |
| (7) NEN heat exchanger[1)] | 100,0% | Not required | 108,2% | 106,9% | Not required | Not required |
| (8) Water separator | 100,0% | Not required | 105,6% | 110,1% | Not required | Not required |
| (9) Air cooler | 100,0% | 88,1% | 106,7% | 108,2% | Not applicable | Not applicable |

1) with fatigue analysis according to EN 13445 and ASME VIII Div. 2, respectively.

2) the minimum plate thickness according to TEMA – applied on both EN and ASME approach – tends to equalize the designs.

d) Overall it is demonstrated that EN 13445 offers a technically and economically competitive design route for unfired pressure vessels. In 6 / 7 (depending on the type of the courses in the case of the hydrogen reactor) out of 9 examples the EN design route was the most economic. It should be noted however that in some cases the reported cost differences for different manufactures are larger than the cost differences resulting from the application of the various codes.

e) Specific factors affecting costs were: Material costs are frequently greater using the ASME code. In some cases, savings attributable to lower material costs with EN 13445 are partly offset by additional costs of weld testing and NDT when compared with ASME requirements. PWHT costs are frequently greater for the ASME designs, since the PWHT requirements depend on the wall thicknesses. For the two standard refinery heat exchangers no notable cost differences are reported if TEMA requirements are considered for all routes.

f) Use of Design-by-Analysis according to EN 13445-3 Annex B can decrease the material costs considerable in some cases, especially for more advanced or complex design or in serial production. The increased design costs are easily compensated by the savings for materials and – if applicable – by the savings of the post weld heat treatment costs.

g) The requirements for ASME vessels which fulfil the PED requirements and are considered to be CE-marked, are based on an agreement between the members of the consortium on the general approach within their organisations to such matters, but they cannot be used as generally valid requirements of conformity assessment for ASME vessels under the PED. Especially, since the ASME approach is not always in conformity with some general rules of PED Annex I.7 and PED Annex I.4.3[1], nor demonstrates an equivalent level of safety. But as given by the cost estimations of the manufacturers, the extra costs for ASME designs to meet the PED requirements are in general small for the approach used in the study.

h) Fatigue design according to ASME Div. VIII Sec. 2 Appendix 5 for welded regions is considered to be non-conservative in comparison with procedures in major European pressure vessel codes (e.g. EN 13445, AD-Merkblatt, PD 5500) and the underlying experimental results. Thus, ASME fatigue design for these regions is not considered to meet the requirements of PED Annex I. Taking this into account, the results of alternative design procedures may be required for fatigue evaluation, i.e. re-assessment of the fatigue life using a European approach would be desirable in practice, but was not performed within this study. However for the purposes of the comparisons made in this project, the costings for the ASME designs involving fatigue do not include extra charges in this respect.

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[1] This provision has been outlined in detail in PED guideline 7/24.

# Annex 1: List of Abbreviations

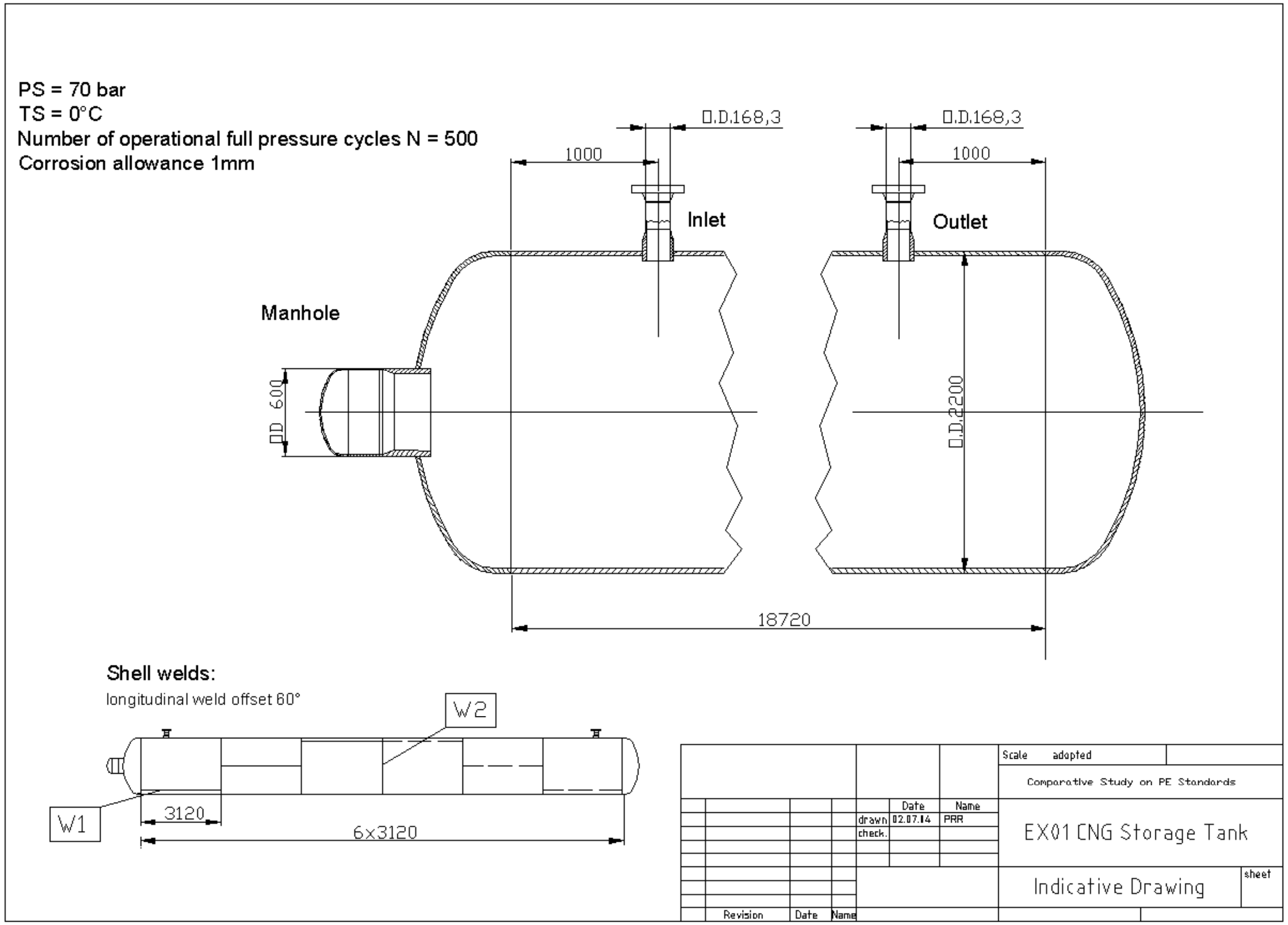
Although mostly given in the text or in the footnotes, the following list summarizes the abbreviations used in the text and in the drawings.

| | |
|---|---|
| AES | TEMA heat exchanger type with (A) channel and removable cover, (E) one pass shell, (S) floating with backing device |
| AD | AD Merkblätter (German code for unfired pressure vessels) |
| ASME | American Society of Mechanical Engineers |
| BEM | TEMA heat exchanger type with (B) bonnet (integral cover), (E) one pass shell, (M) fixed tubesheet like "B" stationary head |
| B&PV | (ASME) Boiler and Pressure Vessel Code |
| DBA | Design by Analysis |
| DBF | Design by Formulae |
| EN 13445 | Harmonised European code for unfired pressure vessels |
| HAZ | Heat effected zone (of a weld) |
| MDMT | Minimum Design Metal Temperature according to B&PV |
| MT | Magnetic particle testing |
| NDT | Non destructive testing |
| NEN | TEMA heat exchanger type with (N) fixed tubesheet like "N" stationary head, (E) one pass shell |
| PD5500 | British code for unfired fusion welded pressure vessels |
| PED | Pressure Equipment Directive |
| PS | Maximum allowable pressure (see EN 13445) |
| PT | Liquid penetration testing |
| PWHT | Post weld heat treatment |
| RT | Radiographic testing |
| TEMA | Tubular Exchanger Manufacturers Association |
| TS | Maximum allowable temperature (see EN 13445) |
| UT | Ultrasonic testing |
| WRC | Welding research council |

# Annex 2 Indicative Drawings and Comparison of Design Results Sheets

On the following pages, an indicative drawing which shows the main dimensions and a comparison sheet which shows the thickness and materials for the different parts of a vessel is given for each example case.

Example 1 CNG Storage Tank: Indicative drawing



PS = 70 bar
TS = 0°C
Number of operational full pressure cycles N = 500
Corrosion allowance 1mm

Shell welds:
longitudinal weld offset 60°

# Example 1 CNG Storage Tank: Comparison of Results Sheet

## Comparision of Results: Comp. Study EX01 (CNG Storage Tank)

| Part | EN 13345-3 DBF | | | EN 13445-3 Annex B DBA | | | ASME VIII/1 | | | + PED | ASME VIII/2 DBF A) | | | ASME VII/2 DBA A) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference 7) | nom. thickness / reference | material | note | nom. thickness / reference | material | note |
| main cyl. shell | 34mm | P460NH<br>EN 10028-3 | | 28.5mm | P460NH<br>EN 10028-3 | GPD contr. 1) | 47,5mm | SA-738 Gr. B | | 51mm | 40mm | SA-738 Gr. B | | 40mm | SA-738 Gr. B | not by stress analysis 5) |
| inlet reinforcements | 28mm<br>Ibi=36mm<br>Ibo=72mm | P355NH<br>EN 10222-4 | | 28mm<br>Ibi=36mm<br>Ibo=70mm | P355NH<br>EN 10222-4 | GPD contr. 1)2) | 31mm<br>Ibi=72.5mm<br>Ibo=75mm | SA-372 Gr. B | | 31mm<br>Ibi=77.5mm<br>Ibo=77.5mm | 28mm<br>Ibi=70mm<br>Ibo=70mm | SA-372 Gr. B | | 28mm<br>Ibi=70mm<br>Ibo=70mm | SA-372 Gr. B | not by stress analysis 5) |
| inlet pipe | 7,1mm | P235GH EN 10216-2 | | 7,1mm | P235GH EN 10216-2 | not by DBA | 7,11mm (STD)<br>ASME B36.10 | SA-106 Gr.B | | unchanged | 10,97mm (XS) 4)<br>ASME B36.10 | SA-106 Gr.B | | 10,97mm (XS) 4)<br>ASME B36.10 | SA-106 Gr.B | not by stress analysis |
| inlet flange | DN150, PN100<br>EN1092-1 | C22.8 (DIN)<br>EN 10222-2 | by EN1092-1 rating | DN150, PN100<br>EN1092-1 | C22.8 (DIN)<br>EN 10222-2 | by EN1092-1 rating | NPS6, Class600<br>ASME B16.5 | SA-105 | by ASME B16.5 rating | unchanged | NPS6, Class600<br>ASME B16.5 | SA-105 | by ASME B16.5 rating | NPS6, Class600<br>ASME B16.5 | SA-105 | by ASME B16.5 rating |
| dished heads | 32mm | P460NH<br>EN 10028-3 | Korbbogen form | 30mm | P460NH<br>EN 10028-3 | Korbbogen form; GPD contr. | 46mm | SA-738 Gr. B | Ellipsodial form 3) | 49mm | 43mm | SA-738 Gr. B | Ellipsodial form 3) | 40mm | SA-738 Gr. B | Ellipsodial form |
| reinforcement manhole | 32mm Ibi=72mm<br>Ibo=146mm | P355NH<br>EN 10222-4 | | 43mm Ibi=80mm<br>Ibo=150mm | P355NH<br>EN 10222-4 | GPD contr. 1)2) | 52mm<br>Ibi=112.5mm<br>Ibo=112.5mm | SA-372 Gr. B | | 52mm<br>Ibi=112.5mm<br>Ibo=120mm | 60mm Ibi=110mm<br>Ibo=110mm | SA-372 Gr. B | | 40mm Ibi=100<br>Ibo=80mm | SA-372 Gr. B | |
| manhole shell | 10,5mm | P460NH<br>EN 10028-3 | | 10,5mm | P460NH<br>EN 10028-3 | not by DBA | 14.5mm | SA-738 Gr. B | | unchanged | 12,5mm 6) | SA-738 Gr. B | | 12,5mm 6) | SA-738 Gr. B | not by stress analysis |
| dished head manhole | 9,5mm | P460NH<br>EN 10028-3 | Korbbogen form | 9,5mm | P460NH<br>EN 10028-3 | Korbbogen form; not by DBA | 13.5mm | SA-738 Gr. B | Ellipsodial form 3) | unchanged | 12.5mm | SA-738 Gr. B | Ellipsodial form 3) | 12.5mm | SA-738 Gr. B | Ellipsodial form; not by stress |

A) No fatigue analysis required according to AD-160; no increase in wall thickness due to the hydrostatic test pressure acc. to the PED

1) The DBA results are based on the global plastic deformation check

2) Fatigue analysis shows that specified number of full pressure cycles is admissible

3) Allowable stress of torispherical heads is limited by 20000psi

4) according to AD-140

5) due to the fact that the thickness of the main shell cannot be decreased by stress analysis

6) no taper necessary, since the same wall thickness as for the shell is adopted

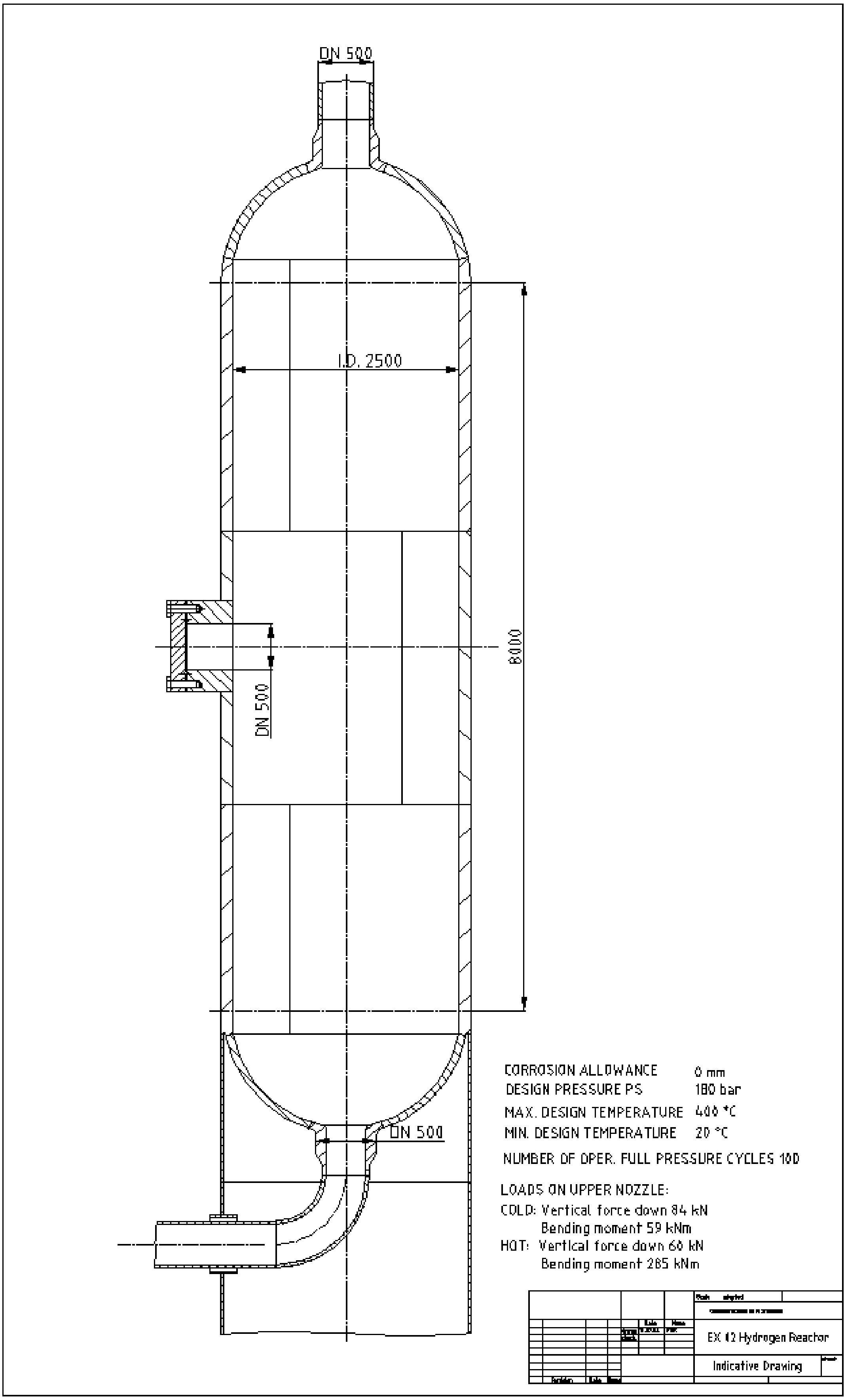
7) based upon the test pressure required by the PED

Thicknesses for ends are minimum values.

Plate tolerance according to EN 10029 class A.

Notes "not by DBA", "not by stress analysis" mean that the thicknesses are chosen for manufacturing reasons or that DBA or a stress analysis is not economical for the part under consideration.

Example 2 Hydrogen Reactor: Indicative drawing



# Example 2 Hydrogen Reactor: Comparison of Results Sheet

**Comparison of Results: EX02 (Hydrogen Reactor)**

| Part | EN 13345-3 DBF (forged course)[B] | | | EN 13345-3 DBF (welded course)[B] [2] | | | ASME VIII/1 (welded [2]/*forged* [C] course) | | | + PED | ASME VIII/2 DBF[A] (welded[2]/*forged* [C] course) | | | ASME VIII/2 App. 4 [A] (welded[2]/*forged* [C] course) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference | nom. thickness / reference | material | note | nom. thickness / reference | material | note[3] |
| main cylindrical shell | 190mm (MW) | 11CrMo9-10<br>EN 10222-2 | | 124mm (MW) | 12CrMo9-10<br>EN 10028-2 | | 181mm (MW) | SA 387 Gr. 22 Cl. 2; *SA 336 F22 Cl. 3* | | 181mm (MW) | 151mm (MW) | SA 387 Gr. 22 Cl. 2; *SA 336 F22 Cl. 3* | | 151mm (MW) | SA 387 Gr. 22 Cl. 2; *SA 336 F22 Cl. 3* | not by stress analysis |
| reinforcement manhole | 250mm<br>ho=320mm | 11CrMo9-10<br>EN 10222-2 | I.D. 500mm | 250mm<br>ho=386mm | 11CrMo9-10<br>EN 10222-2 | I.D. 500mm | 200mm<br>ho=270mm | SA 336 F22 Cl. 3 | I.D. 500mm | 200mm<br>ho=270mm | 180mm<br>ho=255mm | SA 336 F22 Cl. 3 | I.D. 500mm | 180mm<br>ho=255mm | SA 336 F22 Cl. 3 | I.D. 500mm, not by stress |
| cover manhole | 190mm | 11CrMo9-10<br>EN 10222-2 | | 155mm | 12CrMo9-10<br>EN 10028-2 | | 185mm (center)<br>145mm (periphery) | SA 387 Gr. 22 Cl. 2 | | 185mm (center)<br>145mm (periphery) | 160mm (center)<br>108mm (periphery) | SA 387 Gr. 22 Cl. 2 | | 160mm (center)<br>108mm (periphery) | SA 387 Gr. 22 Cl. 2 | not by stress analysis |
| upper spherical head | 110mm (MW) | 11CrMo9-10<br>EN 10222-2 | inside crown radius 1275mm | 100mm (MW) | 12CrMo9-10<br>EN 10028-2 | inside crown radius 1275mm | 86mm (MW) | SA 387 Gr. 22 Cl. 2; *SA 336 F22 Cl. 3* | inside crown radius 1275mm | 86mm (MW) | 75 mm (MW) | SA 387 Gr. 22 Cl. 2; *SA 336 F22 Cl. 3* | inside crown radius 1275mm | 75 mm (MW) | SA 387 Gr. 22 Cl. 2; *SA 336 F22 Cl. 3* | inside crown radius 1275mm; not by stress analysis |
| upper nozzle reinforcements | 130mm<br>ho=295mm | 11CrMo9-10<br>EN 10222-2 | I.D. 520mm; check acc. to EN 13445-3, cl. 16[1] | 100mm<br>ho=250mm | 11CrMo9-10<br>EN 10222-2 | I.D. 520mm; check acc. to EN 13445-3, cl. 16[1] | 145mm<br>ho=215mm<br>corner radius r= 50mm; I.D. 504.86mm | SA 336 F22 Cl. 3 | I.D. 504.86mm; check acc. to WRC 107 | 145mm<br>ho=215mm<br>corner radius r= 50mm; I.D. 490.52mm | 142mm<br>ho=187.5mm<br>corner radius = 37,5mm | SA 336 F22 Cl. 3 | I.D. 504.86mm; check acc. to WRC 107 | 120mm<br>ho=185mm | SA-372 Gr. B | I.D. 504.86mm; by stress anaylsis |
| upper nozzle pipe | 590x45mm | 11CrMo9-10 NT EN 10216-2 | I.D. 520mm | 590x45mm | 11CrMo9-10 NT EN 10216-2 | I.D. 520mm | 609,6x52,37mm (Sch 140) ASME B36.10 | SA 335 P22 | I.D. 504.86mm | 609,6x59,54mm (Sch 160) ASME B36.10 | 609,6x52,37mm (Sch 140) ASME B36.10 | SA 335 P22 | I.D. 504.86mm; acc. to (VIII/1 and) connected piping | 609,6x52,37mm (Sch 140) ASME B36.10 | SA 335 P22 | I.D. 504.86mm; acc. to (VIII/1 and) connected piping |
| lower spherical head | 100mm (MW) | 11CrMo9-10<br>EN 10222-2 | inside crown radius 1275mm | 75mm (MW) | 12CrMo9-10<br>EN 10028-2 | inside crown radius 1275mm | 86mm (MW) | SA 387 Gr. 22 Cl. 2; *SA 336 F22 Cl. 3* | inside crown radius 1275mm | 86mm (MW) | 75 mm (MW) | SA 387 Gr. 22 Cl. 2; *SA 336 F22 Cl. 3* | inside crown radius 1275mm | 75 mm (MW) | SA 387 Gr. 22 Cl. 2; *SA 336 F22 Cl. 3* | inside crown radius 1275mm; not by stress analysis |
| lower nozzle reinforcements | 100mm<br>ho=250mm | 11CrMo9-10<br>EN 10222-2 | I.D. 444mm | 110mm<br>ho=250mm | 11CrMo9-10<br>EN 10222-2 | I.D. 444mm | 118mm ho=215mm<br>corner radius r= 50mm | SA 336 F22 Cl. 3 | I.D. 419.1mm | 118mm<br>ho=215mm<br>corner radius r= 50mm | 118mm<br>ho=187.5mm<br>corner radius = 37,5mm | SA 336 F22 Cl. 3 | I.D. 419.1mm | 118mm<br>ho=187.5mm<br>corner radius = 37,5mm | SA 336 F22 Cl. 3 | I.D. 419.1mm; not by stress analysis |
| lower nozzle pipe bend | 32mm<br>acc. to<br>EN 13480-3 | 11 CrMo9-10 NT EN 10216-2 | I.D. 444mm | 32mm<br>acc. to<br>EN 13480-3 | 11 CrMo9-10 NT EN 10216-2 | I.D. 444mm | 20", Sch 140, acc. to ASME B16.9 | SA 234 WP22 | | 20", Sch 140, acc. to ASME B16.9 | 20", Sch 140, acc. to ASME B16.9 | SA 234 WP22 | acc. to connected piping | 20", Sch 140, acc. to ASME B16.9 | SA 234 WP22 | acc. to connected piping |
| lower nozzle pipe | 508x32mm | 11CrMo9-10 NT EN 10216-2 | I.D. 444mm | 508x32mm | 11CrMo9-10 NT EN 10216-2 | I.D. 444mm | 508x44.5mm (Sch 140) ASME B36.10 | SA 335 P22 | I.D. 419.1mm | 508x44.5mm (Sch 140) ASME B36.10 | 508x44.5mm (Sch 140) ASME B36.10 | SA 335 P22 | I.D. 419.1mm; acc. to (VIII/1 and) connected piping | 508x44.5mm (Sch 140) ASME B36.10 | SA 335 P22 | I.D. 419.1mm; acc. to (VIII/1 and) connected piping |
| skirt upper part | 22mm | 13 CrMo4-5<br>EN 10028-2 | I.D. 2876mm | 22mm | 13 CrMo4-5<br>EN 10028-2 | I.D. 2876mm | 15mm | SA 387 Gr. 22 Cl. 2 | design as for ASME VIII Div. 2 | 15mm | 15mm | SA 387 Gr. 22 Cl. 2 | | 15mm | SA 387 Gr. 22 Cl. 2 | not by stress analysis |
| skirt lower part | 22mm | P265GH<br>EN 10028-2 | I.D. 2876mm | 22mm | P265GH<br>EN 10028-2 | I.D. 2876mm | 15mm | SA-285 Gr. C | | 15mm | 15mm | SA-285 Gr. C | | 15mm | SA-285 Gr. C | |

[A] No fatigue analysis required according to AD-160

[B] DBA does not render reduced wall thicknesses for the upper head

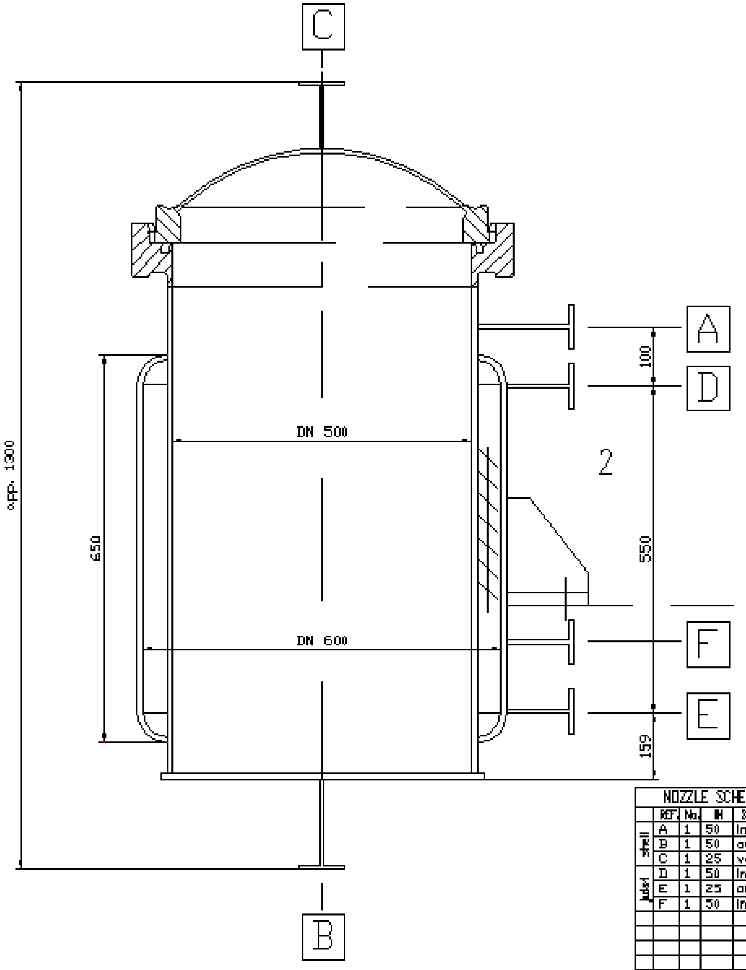
[C] *Forged parts given in italic letters*

[1] Design gouverned by nozzle loads

[2] Plate manufacturing tol. acc. to EN 10029 class C (0 mm undertolerance)

[3] "not by stress analysis" means that the thicknesses are chosen for manufacturing reasons ot that stress analysis is not economical or does not lead to decreased thicknesses.

Example 3 Autoclave: Indicative drawing



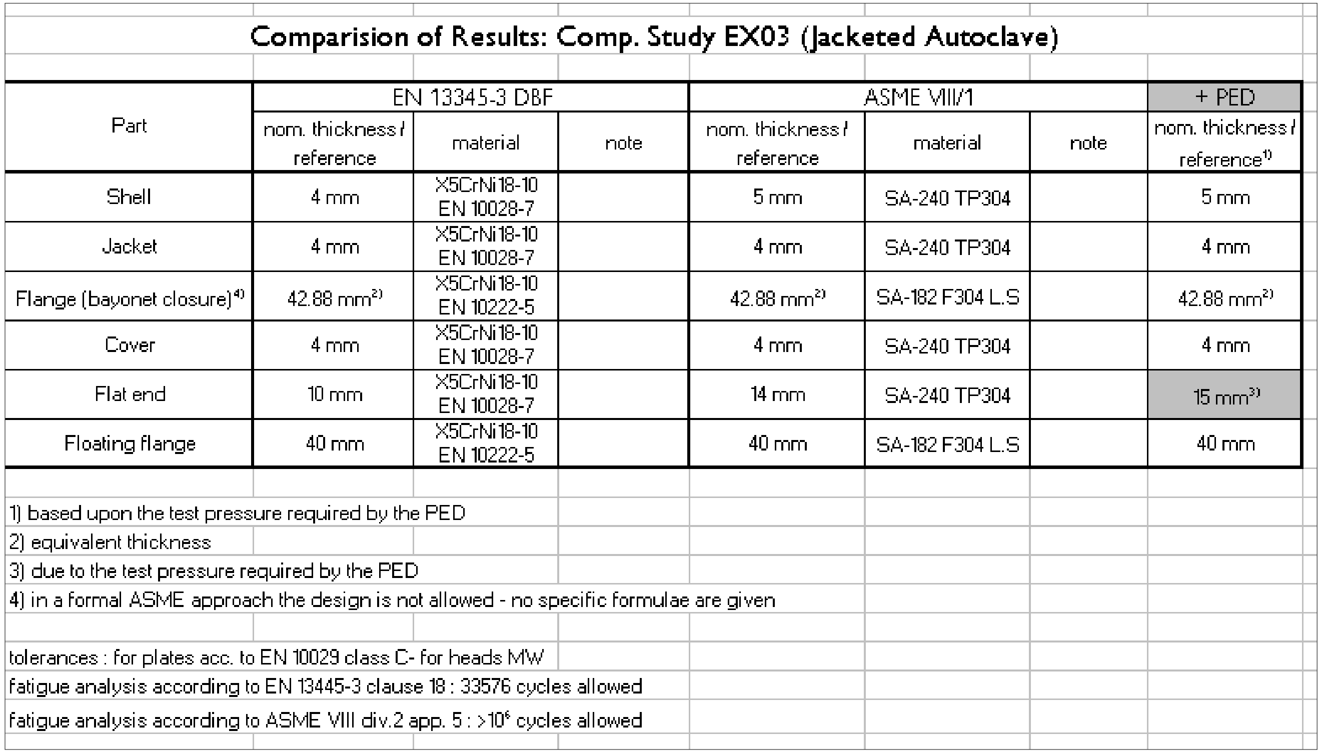
| DESIGN DATA | | SHELL | JACKET |
|---|---|---|---|
| DESIGN PRESS. | bar | 2.7/-1 | 4 |
| DESIGN TEMPERAT. | °C | 150 | 20 |
| CORROSION ALLOW. | mm | 0 | 0 |
| FATIGUE ANALYSIS FOR THERMAL CYCLES REQUIRED | | | |

| NOZZLE SCHEDULE | | | | |
|---|---|---|---|---|
| | REF. | No. | DN | SERVICE |
| shell | A | 1 | 50 | inlet |
| | B | 1 | 50 | outlet |
| | C | 1 | 25 | vent |
| jacket | D | 1 | 50 | inlet |
| | E | 1 | 25 | outlet |
| | F | 1 | 50 | inspect. |

| | | | | |
|---|---|---|---|---|
| △ | | | | |
| △ | | | | |
| △ | | | | |
| A | | | | |
| REV. | DESCRIPTION | DRAWN | CHECKED | APPROV. |

CLIENT & LOCATION:
PLANT:
UNIT:
REQUISITION N°:
SERVICE:
ITEM: Ex03 Autoclave
JOB N°: Indicative Drawing
DATE: 0607/2004
REV.:
N° REQ.D 1
DWG. N°:

Example 3 Autoclave: Comparison of Results Sheet



**Comparision of Results: Comp. Study EX03 (Jacketed Autoclave)**

| Part | EN 13345-3 DBF | | | ASME VIII/1 | | | + PED |
|---|---|---|---|---|---|---|---|
| | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference[1] |
| Shell | 4 mm | X5CrNi18-10<br>EN 10028-7 | | 5 mm | SA-240 TP304 | | 5 mm |
| Jacket | 4 mm | X5CrNi18-10<br>EN 10028-7 | | 4 mm | SA-240 TP304 | | 4 mm |
| Flange (bayonet closure)[4] | 42.88 mm[2] | X5CrNi18-10<br>EN 10222-5 | | 42.88 mm[2] | SA-182 F304 L.S | | 42.88 mm[2] |
| Cover | 4 mm | X5CrNi18-10<br>EN 10028-7 | | 4 mm | SA-240 TP304 | | 4 mm |
| Flat end | 10 mm | X5CrNi18-10<br>EN 10028-7 | | 14 mm | SA-240 TP304 | | 15 mm[3] |
| Floating flange | 40 mm | X5CrNi18-10<br>EN 10222-5 | | 40 mm | SA-182 F304 L.S | | 40 mm |

1) based upon the test pressure required by the PED

2) equivalent thickness

3) due to the test pressure required by the PED

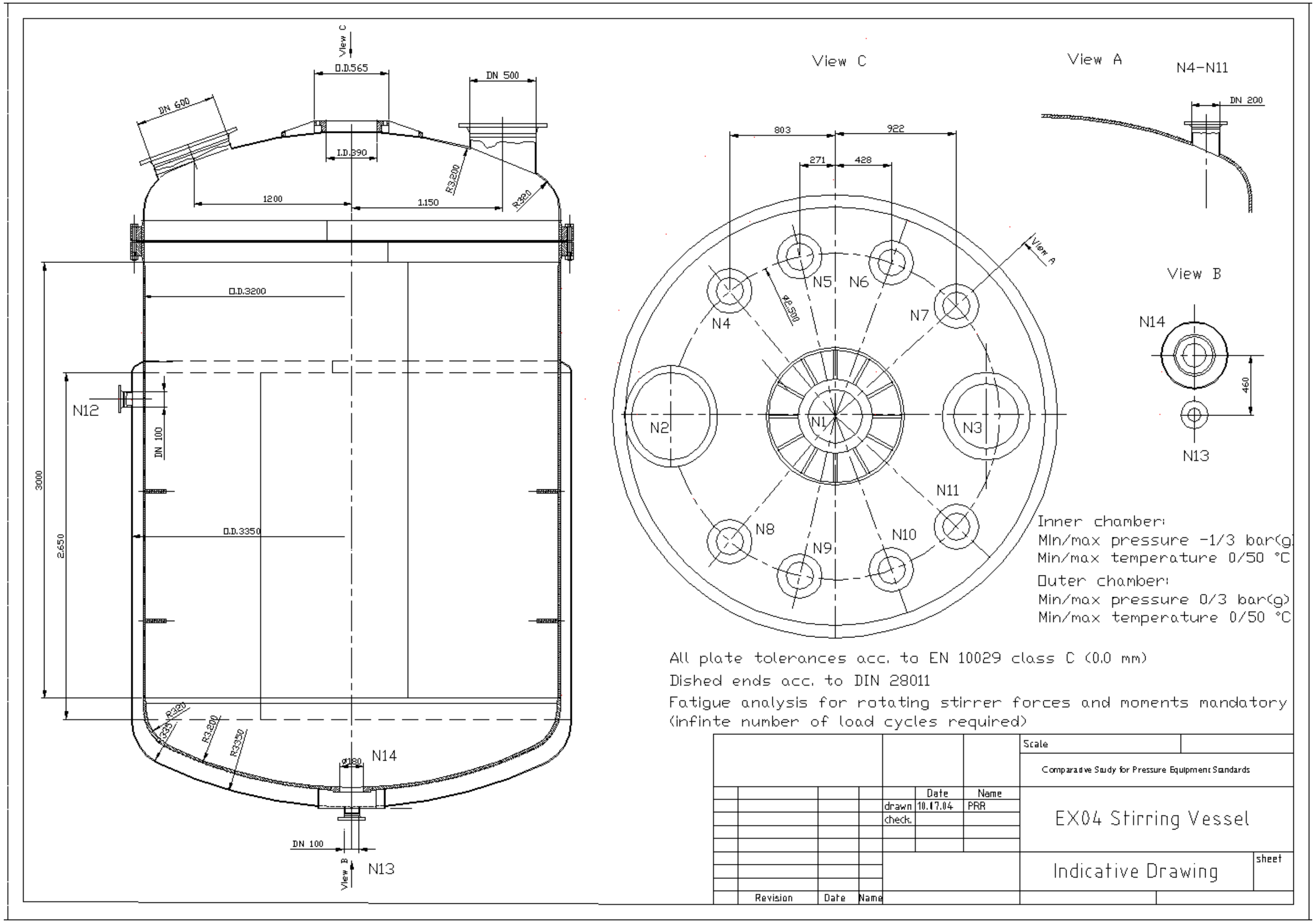
4) in a formal ASME approach the design is not allowed - no specific formulae are given

tolerances : for plates acc. to EN 10029 class C- for heads MW

fatigue analysis according to EN 13445-3 clause 18 : 33576 cycles allowed

fatigue analysis according to ASME VIII div.2 app. 5 : >$10^6$ cycles allowed

Example 4 Stirring Vessel: Indicative drawing



Inner chamber:
MIn/max pressure -1/3 bar(g)
Min/max temperature 0/50 °C

Outer chamber:
Min/max pressure 0/3 bar(g)
Min/max temperature 0/50 °C

All plate tolerances acc. to EN 10029 class C (0.0 mm)

Dished ends acc. to DIN 28011

Fatigue analysis for rotating stirrer forces and moments mandatory
(infinte number of load cycles required)

| | Date | Name |
|---|---|---|
| drawn | 10.17.04 | PRR |
| check. | | |

Revision | Date | Name

Scale

Comparative Study for Pressure Equipment Standards

EX04 Stirring Vessel

Indicative Drawing

sheet

# Example 4 Stirring Vessel: Comparison of Results Sheet

**Comparison of Results: Comp. Study EX04 (Stirring Vessel)**

| Part | EN 13345-3 DBF + Fatigue[1] | | | ASME VIII/1 + Fatigue[2] | | | + PED |
|---|---|---|---|---|---|---|---|
| | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference |
| upper dished head (Klöpperboden-form) | 10mm[5] | X6CrNiTi17-12-2<br>EN 10028-7 | Design for an infinite number of stirrer load cycles[3]. Allowable number of batch cycles: N=13100. Flanges acc. to rating in EN1092-1 | 12.5mm | SA-240 Gr. 316Ti | Design for an infinite number of stirrer load cycles[4]. Allowable number of batch cycles: N=2x$10^8$. Flanges acc. to rating in ASME B16.5 | 12.5mm |
| mounting flange (N1) | DIN 28137-AN400 | X6CrNiTi17-12-2<br>EN 10222-5 | | DIN 28137-AN400 | SA-182 Gr. 316L | | DIN 28137-AN400 |
| mounting flange (N1) reinforcement (stirrer actions) | Ribs: number=12, thickness 20mm, length 210mm, height 90/20mm. Ring: O.D. 1025mm, section 20x20mm | X6CrNiTi17-12-2<br>EN 10028-7 | | Ribs: number=8, thickness 15mm, length 95mm, height 90/15mm. Ring: O.D. 785mm, section 15x15mm | SA-240 Gr. 316Ti | | Ribs: number=8, thickness 15mm, length 95mm, height 90/15mm. Ring: O.D. 785mm, section 15x15mm |
| manhole nozzle (N2) | 609,6x8mm | X6CrNiTi17-12-2<br>EN 10028-7 | | 609,6x18mm | SA-240 Gr. 316Ti | | 609,6x18mm |
| manhole flange (N2) | DN600, PN6<br>EN1092-1 | X6CrNiTi17-12-2<br>EN 10222-5 | | NPS24, Class 150<br>ASME B16.5 | SA-182 Gr. 316L | | NPS24, Class 150<br>ASME B16.5 |
| nozzle N3 | 508x8mm | X6CrNiTi17-12-2<br>EN 10028-7 | | 508x16mm | SA-240 Gr. 316Ti | | 508x16mm |
| flange nozzle N3 | DN500, PN6<br>EN1092-1 | X6CrNiTi17-12-2<br>EN 10222-5 | | NPS20, Class 150<br>ASME B16.5 | SA-182 Gr. 316L | | NPS20, Class 150<br>ASME B16.5 |
| nozzles N4 - N11 | 219,1x6,3mm | X6CrNiTi17-12-2<br>prEN 10216-5 | | 219,1x12,7 (XS)<br>ASME B36.10 | SA-312 Gr. 316L | | 219,1x12,7 (XS)<br>ASME B36.10 |
| flange nozzles N4 - N11 | DN200, PN6<br>EN1092-1 | X6CrNiTi17-12-2<br>EN 10222-5 | | NPS8, Class 150<br>ASME B16.5 | SA-182 Gr. 316L | | NPS8, Class 150<br>ASME B16.5 |
| shell flange | DIN 28038 CD<br>3200x105<br>P235GH<br>X6CrNiTi17-12-2 | P235GH<br>EN10222-2;<br>X6CrNiTi17-12-2<br>EN 10028-7;<br>stainl. steel cladding | | DIN 28038 CD<br>3200x105<br>SA-105<br>SA-240 Gr. 316Ti | SA-105;<br>SA-312 Gr. 316Ti;<br>stainless steel cladding | | DIN 28038 CD<br>3200x105<br>SA-105<br>SA-240 Gr. 316Ti |
| lower part - cyl. shell (inside) | 11mm | X6CrNiTi17-12-2<br>EN 10028-7 | z=0.85 | 15mm | SA-240 Gr. 316Ti | E=0.70 circumf. stress | 15mm |
| reinforcement lower part - cyl. shell (inside) | Rings: number=2, 25x125mm, location: inside | X6CrNiTi17-12-2<br>EN 10028-7 | | Rings: number=2, 30x160mm, location: inside | SA-240 Gr. 316Ti | | Rings: number=2, 30x160mm, location: inside |
| lower part - dished head (inside) (Klöpperboden-form) | 15mm | X6CrNiTi17-12-2<br>EN 10028-7 | | 23mm | SA-240 Gr. 316Ti | E=1.0 smls. Head | 23mm |
| block flange N12 | DIN 28140 - A150 | X6CrNiTi17-12-2<br>EN 10222-5 | | DIN 28140 - A150 | SA-182 Gr. 316L | | DIN 28140 - A150 |
| lower part - cyl. shell (jacket) | 5mm | X6CrNiTi17-12-2<br>EN 10028-7 | z=0.85 | 6mm | SA-240 Gr. 316Ti | E=0.85 circumf. stress | 6mm |
| lower part - dished head (jacket) (Klöpperboden-form) | 10mm | X6CrNiTi17-12-2<br>EN 10028-7 | | 7mm | SA-240 Gr. 316Ti | E=1.0 smls. head | 7,5mm[6] |
| (lower) jacket closure ring | 10mm | X6CrNiTi17-12-2<br>EN 10028-7 | z=0.85 | 7mm | SA-240 Gr. 316Ti | E=0.85 circumf. stress | 7mm |
| (upper) jacket closure | 5mm | X6CrNiTi17-12-2<br>EN 10028-7 | | 6mm | SA-240 Gr. 316Ti | | 6mm |
| nozzles N12 - N13 | 114,3x3,6mm | X6CrNiTi17-12-2<br>prEN 10216-5 | | 114,3x8,56 (XS)<br>ASME B36.10 | SA-312 Gr. 316L | | for N12 a reinforcing pad (5 x 30) is required[6] |
| flange nozzles N12 - N13 | DN100, PN6<br>EN1092-1 | X6CrNiTi17-12-2<br>EN 10222-5 | Flange acc. to rating in EN1092-1 | NPS4, Class150<br>ASME B16.5 | SA-182 Gr. 316L | Flange acc. to rating in ASME B16.5 | NPS4, Class150<br>ASME B16.5 |

[1] Fatigue acc. to clause 18: design for an infinite number of stirrer load cycles; calculation of the allowable number of batch (pressure-) cycles for the upper dished head.

[2] Fatigue acc. to Appendix 5 of Sec. VIII Div. 2: design for an infinite number of stirrer load cycles; calculation of the allowable number of batch (pressure-) cycles for the upper dished head. Results depended fom FE-model details (weld details, mesh size, etc.).

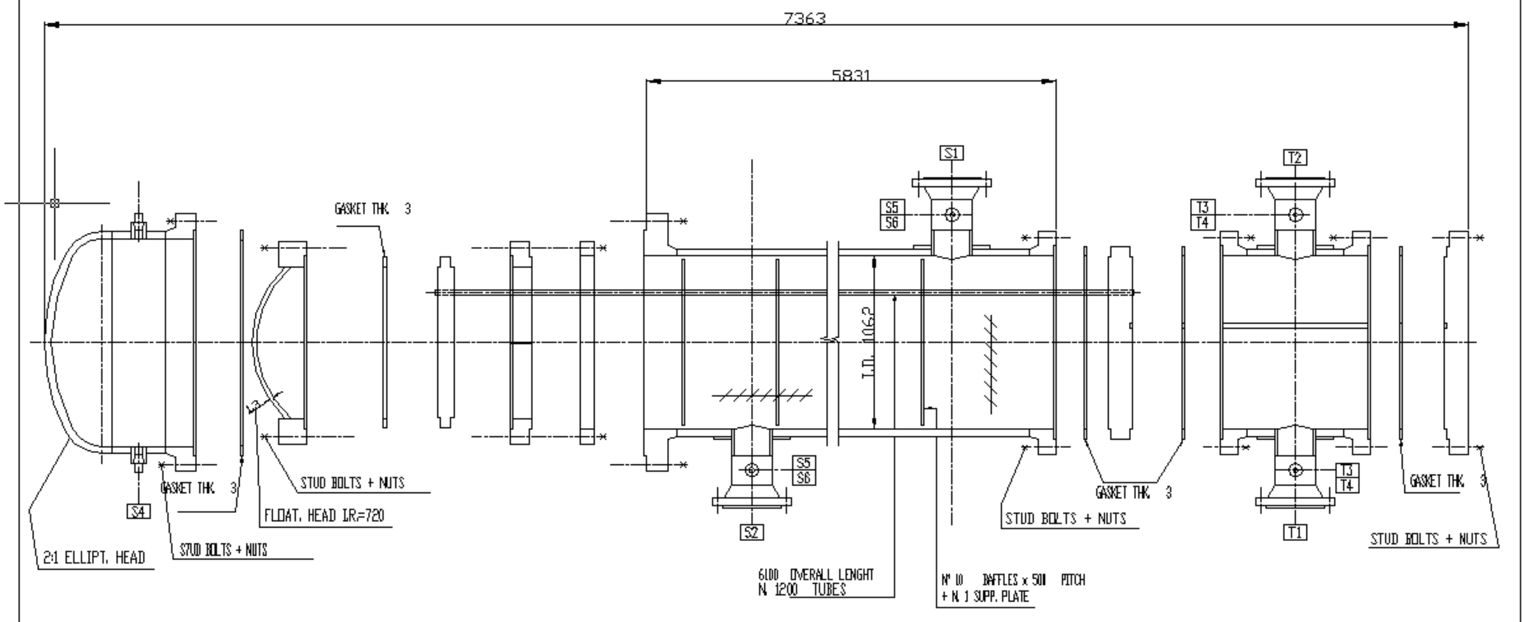
[3] 5x$10^6$ cylces acc. to EN 13445-3 clause 18.

[4] $10^{11}$ cycles acc. to ASME VIII Div.2 Appendix 5.

[5] Due to fatigue requirements

[6] requirements due to the test pressure acc. to the PED

Example 5 AES Heat Exchanger: Indicative drawing



| DESIGN DATA | | SHELL | TUBE |
|---|---|---|---|
| DESIGN PRESS. | bar | 10 | 20 |
| DESIGN TENPERAT. | °C | 200,00 | 200,00 |
| CORROSION ALLOW. | mm | 3 | 3 |
| 500 operational cycles | | | |
| | | | |
| | | | |
| | | | |
| | | | |

NOZZLE SCHEDULE

| | REF. | No. | DN | | | | SERVICE |
|---|---|---|---|---|---|---|---|
| SHELL SIDE | S1 | 1 | 250 | | | | INLET |
| | S2 | 1 | 250 | | | | OUTLET |
| | S3 | 1 | 1" | | | | VENT |
| | S4 | 1 | 1" | | | | DRAIN |
| | S5 | 2 | 1" | | | | THERMOWELL |
| | S6 | 2 | 3/4" | | | | PRESSURE |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| TUBE SIDE | T1 | 1 | 250 | | | | INLET |
| | T2 | 1 | 250 | | | | OUTLET |
| | T3 | 2 | 1" | | | | THERMOWELL |
| | T4 | 2 | 3/4" | | | | PRESSURE |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
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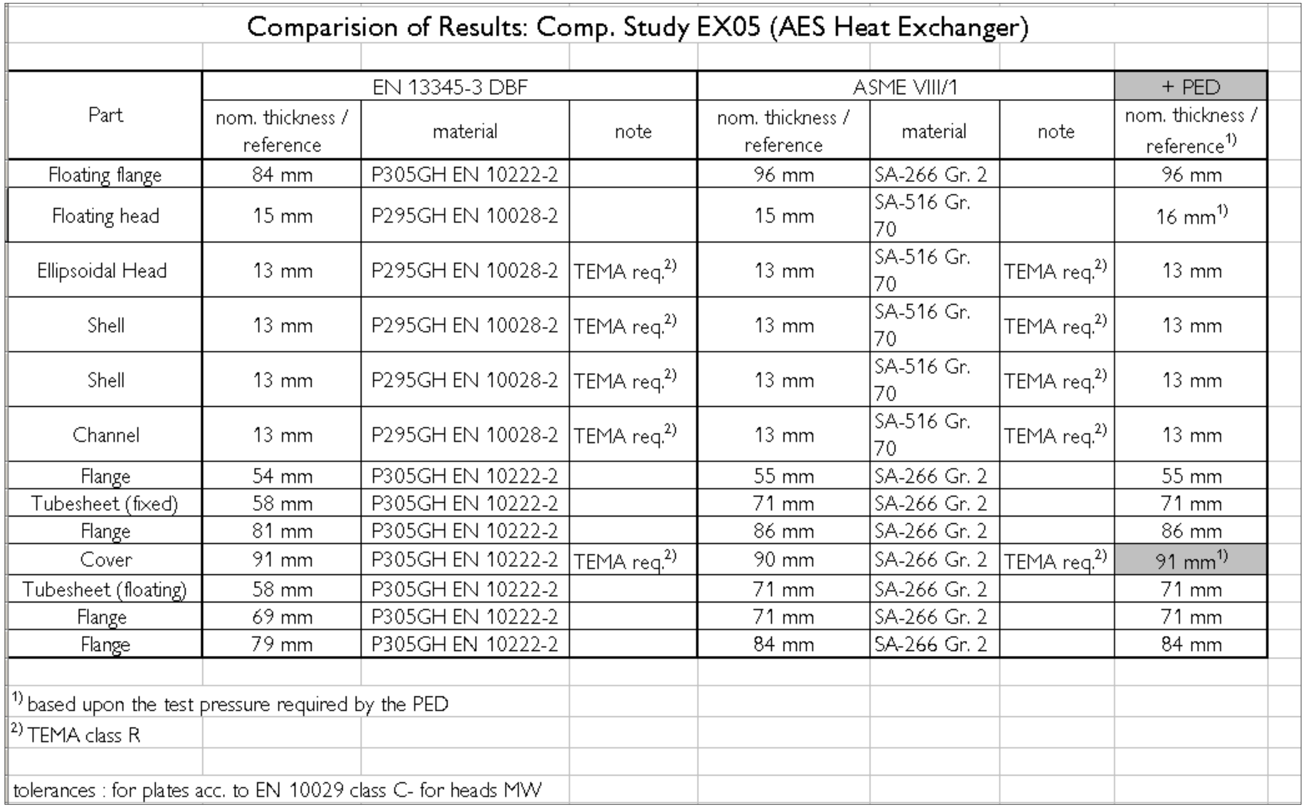
|---|---|---|---|---|
| △ | | | | |
| △ | | | | |
| △ | | | | |
| A | | S.A. | | |
| REV. | DESCRIPTION | DRAWN | CHECKED | APPROV. |

CLIENT & LOCATION:
PLANT:
UNIT:
REQUISITION N°:
SERVICE:

| | | |
|---|---|---|
| Comparative Study on PE Standards<br>EX05 Heat Exchanger | | Indicative Drawing |
| | | DATE 22/01/2004 REV: A |
| N° REQ.D: 1 | TEMA TYPE: AES | DWG. N°: |

Example 5 AES Heat Exchanger: Comparison of Results Sheet



**Comparision of Results: Comp. Study EX05 (AES Heat Exchanger)**

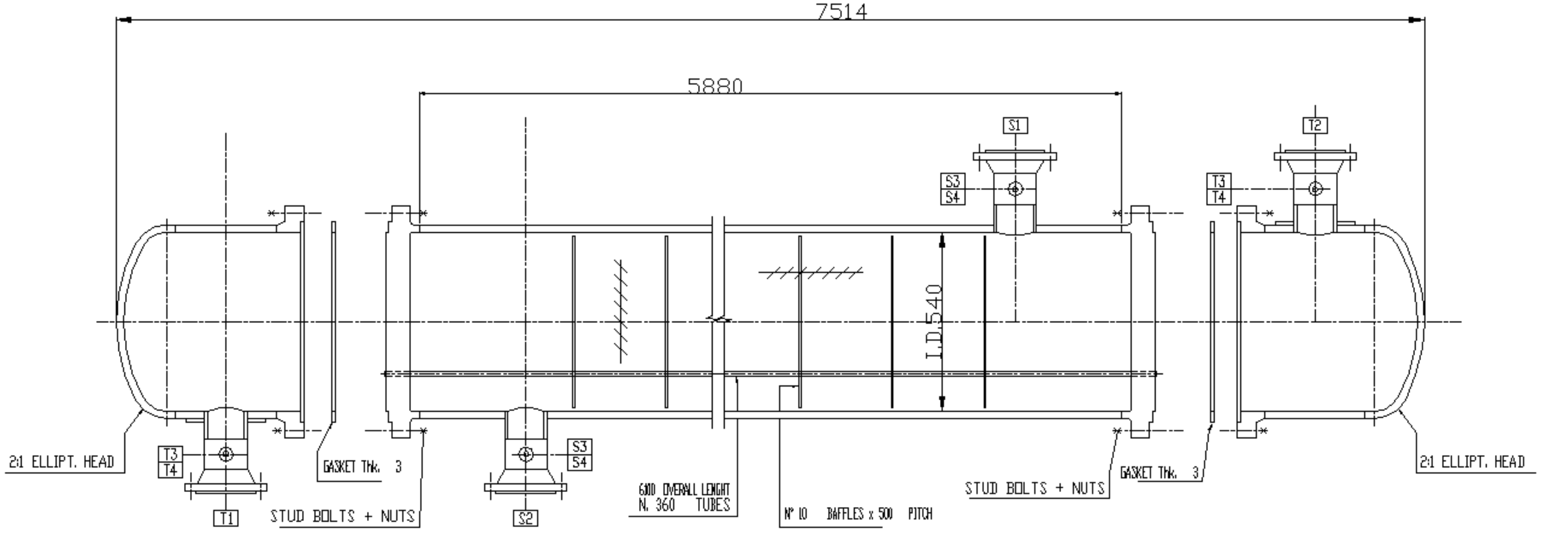
| Part | EN 13345-3 DBF | | | ASME VIII/1 | | | + PED |
|---|---|---|---|---|---|---|---|
| | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference[1] |
| Floating flange | 84 mm | P305GH EN 10222-2 | | 96 mm | SA-266 Gr. 2 | | 96 mm |
| Floating head | 15 mm | P295GH EN 10028-2 | | 15 mm | SA-516 Gr. 70 | | 16 mm[1] |
| Ellipsoidal Head | 13 mm | P295GH EN 10028-2 | TEMA req.[2] | 13 mm | SA-516 Gr. 70 | TEMA req.[2] | 13 mm |
| Shell | 13 mm | P295GH EN 10028-2 | TEMA req.[2] | 13 mm | SA-516 Gr. 70 | TEMA req.[2] | 13 mm |
| Shell | 13 mm | P295GH EN 10028-2 | TEMA req.[2] | 13 mm | SA-516 Gr. 70 | TEMA req.[2] | 13 mm |
| Channel | 13 mm | P295GH EN 10028-2 | TEMA req.[2] | 13 mm | SA-516 Gr. 70 | TEMA req.[2] | 13 mm |
| Flange | 54 mm | P305GH EN 10222-2 | | 55 mm | SA-266 Gr. 2 | | 55 mm |
| Tubesheet (fixed) | 58 mm | P305GH EN 10222-2 | | 71 mm | SA-266 Gr. 2 | | 71 mm |
| Flange | 81 mm | P305GH EN 10222-2 | | 86 mm | SA-266 Gr. 2 | | 86 mm |
| Cover | 91 mm | P305GH EN 10222-2 | TEMA req.[2] | 90 mm | SA-266 Gr. 2 | TEMA req.[2] | 91 mm[1] |
| Tubesheet (floating) | 58 mm | P305GH EN 10222-2 | | 71 mm | SA-266 Gr. 2 | | 71 mm |
| Flange | 69 mm | P305GH EN 10222-2 | | 71 mm | SA-266 Gr. 2 | | 71 mm |
| Flange | 79 mm | P305GH EN 10222-2 | | 84 mm | SA-266 Gr. 2 | | 84 mm |

[1] based upon the test pressure required by the PED

[2] TEMA class R

tolerances : for plates acc. to EN 10029 class C- for heads MW

Example 6 BEM Heat Exchanger: Indicative drawing



| DESIGN DATA | | SHELL | TUBE |
|---|---|---|---|
| DESIGN PRESS. | bar | 10 | 20 |
| DESIGN TEMPERAT. | °C | 200.00 | 200.00 |
| CORROSION ALLOW. | mm | 3 | 3 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

NOTES:

TUBE TO TUBESHEET JOINT:WELDED AND EXP. WITH GROOVES
500 OPERATIONAL CYCLES

NOZZLE SCHEDULE

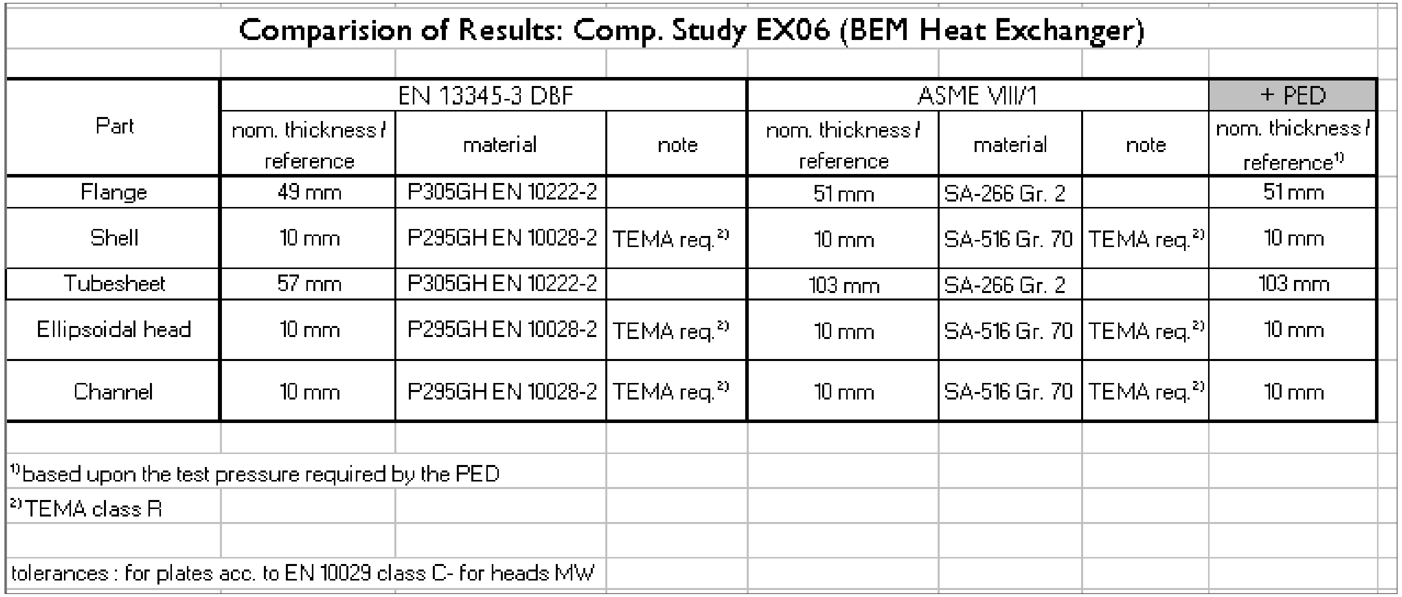
| | REF. | No. | DN | | | | SERVICE |
|---|---|---|---|---|---|---|---|
| SHELL SIDE | S1 | 1 | 150 | | | | INLET |
| | S2 | 1 | 150 | | | | OUTLET |
| | S3 | 2 | 1" | | | | THERMOWELL |
| | S4 | 2 | 3/4" | | | | PRESSURE |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| TUBE SIDE | T1 | 1 | 250 | | | | INLET |
| | T2 | 1 | 250 | | | | OUTLET |
| | T3 | 2 | 1" | | | | THERMOWELL |
| | T4 | 2 | 3/4" | | | | PRESSURE |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

| REV. | DESCRIPTION | DRAWN | CHECKED | APPROV. |
|---|---|---|---|---|
| △ | | | | |
| △ | | | | |
| △ | | | | |
| △A | ISSUED FOR QUOTATION | S.A. | | |

CLIENT & LOCATION:
PLANT:
UNIT:
REQUISITION N°:
SERVICE:

| | |
|---|---|
| Comparative Study on PE Standards<br>EX06 Heat Exchanger | Indicative Drawing<br>DATE: 26/09/2003 REV: A |
| N° REQ.D: 1 \| TEMA TYPE: BEM | DWG. N° |

Example 6 BEM Heat Exchanger: Comparison of Results Sheet



**Comparision of Results: Comp. Study EX06 (BEM Heat Exchanger)**

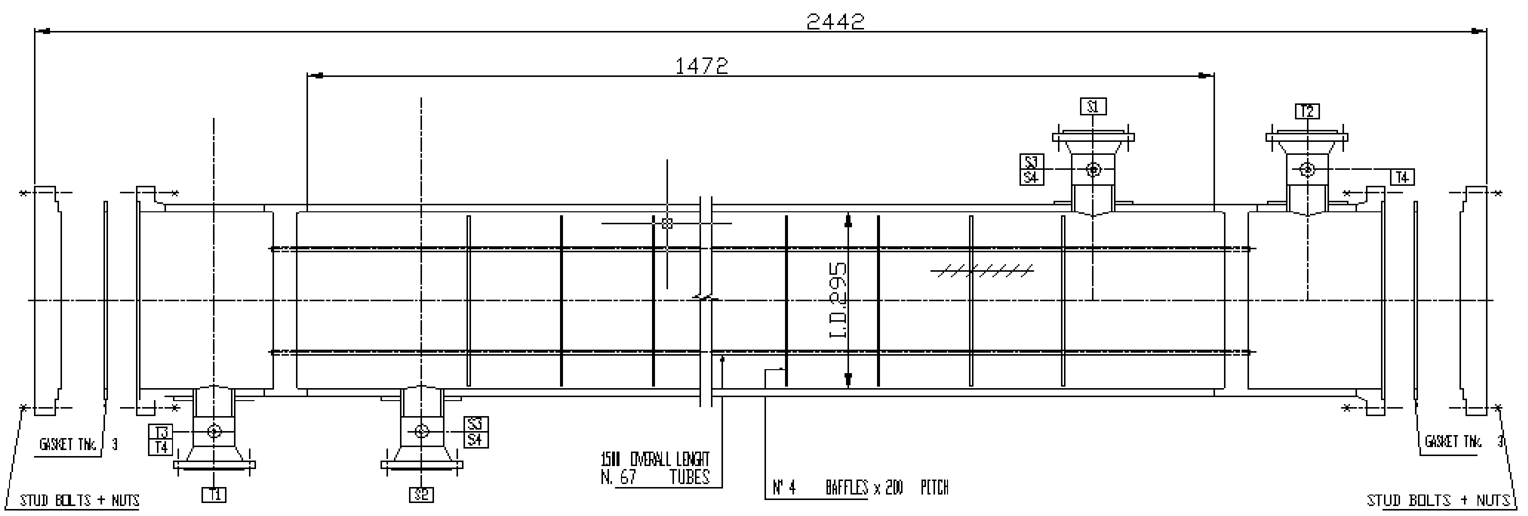
| Part | EN 13345-3 DBF | | | ASME VIII/1 | | | + PED |
|---|---|---|---|---|---|---|---|
| | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference[1] |
| Flange | 49 mm | P305GH EN 10222-2 | | 51 mm | SA-266 Gr. 2 | | 51 mm |
| Shell | 10 mm | P295GH EN 10028-2 | TEMA req.[2] | 10 mm | SA-516 Gr. 70 | TEMA req.[2] | 10 mm |
| Tubesheet | 57 mm | P305GH EN 10222-2 | | 103 mm | SA-266 Gr. 2 | | 103 mm |
| Ellipsoidal head | 10 mm | P295GH EN 10028-2 | TEMA req.[2] | 10 mm | SA-516 Gr. 70 | TEMA req.[2] | 10 mm |
| Channel | 10 mm | P295GH EN 10028-2 | TEMA req.[2] | 10 mm | SA-516 Gr. 70 | TEMA req.[2] | 10 mm |

[1] based upon the test pressure required by the PED

[2] TEMA class R

tolerances : for plates acc. to EN 10029 class C- for heads MW

## Example 7 NEN Heat Exchanger: Indicative drawing



NOTES:

TUBE TO TUBESHEET JOINT: WELDED
10000 OPERATIONAL CYCLES

| DESIGN DATA | | SHELL | TUBE |
|---|---|---|---|
| DESIGN PRESS. | bar | 6 | 2 |
| DESIGN TEMPERAT. | °C | 190/0 | 150/0 |
| CORROSION ALLOW. | mm | 1 | 0 |

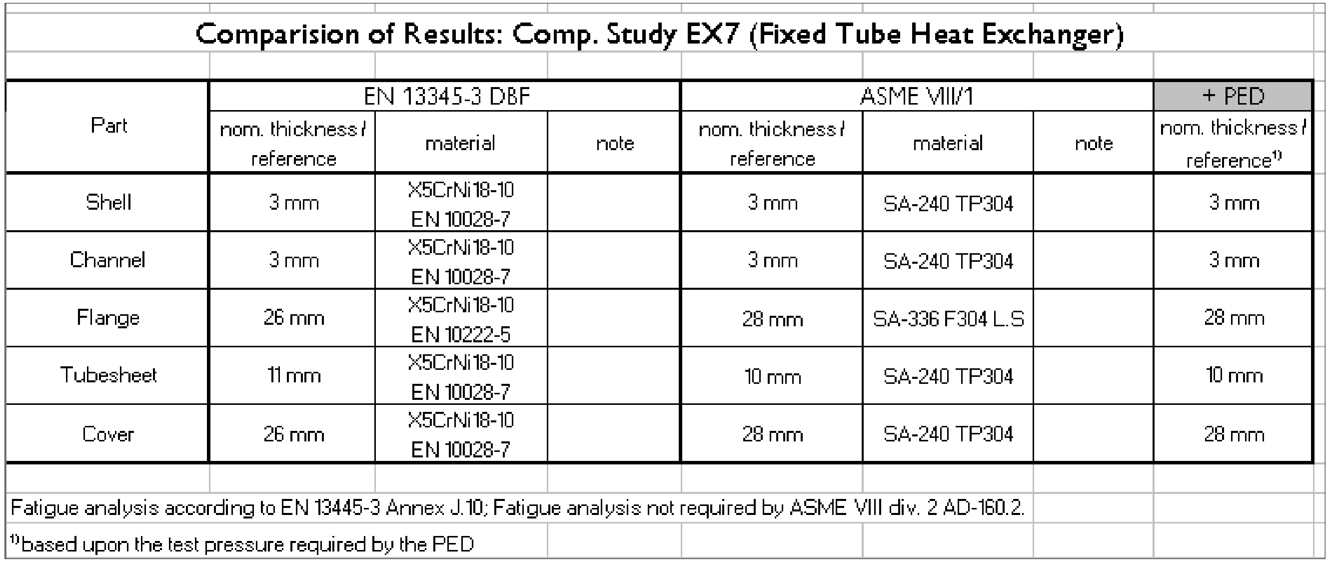
NOZZLE SCHEDULE

| | REF. | No. | DN | | | | SERVICE |
|---|---|---|---|---|---|---|---|
| SHELL SIDE | S1 | 1 | 100 | | | | INLET |
| | S2 | 1 | 100 | | | | OUTLET |
| | S3 | 2 | 1" | | | | THERMOWELL |
| | S4 | 2 | 3/4" | | | | PRESSURE |
| TUBE SIDE | T1 | 1 | 150 | | | | INLET |
| | T2 | 1 | 150 | | | | OUTLET |
| | T3 | 2 | 1" | | | | THERMOWELL |
| | T4 | 2 | 3/4" | | | | PRESSURE |

| REV. | DESCRIPTION | DRAWN | CHECKED | APPROV. |
|---|---|---|---|---|
| △ | | | | |
| △ | | | | |
| △ | | | | |
| A | ISSUED FOR QUOTATION | S.A. | | |

CLIENT & LOCATION:
PLANT:
UNIT:
REQUISITION N°:
SERVICE:
ITEM: EX07 Heat Exchanger
JOB N°: Indicative Drawing
DATE:
REV.: A
N° REQ'D: 1
TEMA TYPE: NEN
DWG. N°:

Example 7 NEN Heat Exchanger: Comparison of Results Sheet



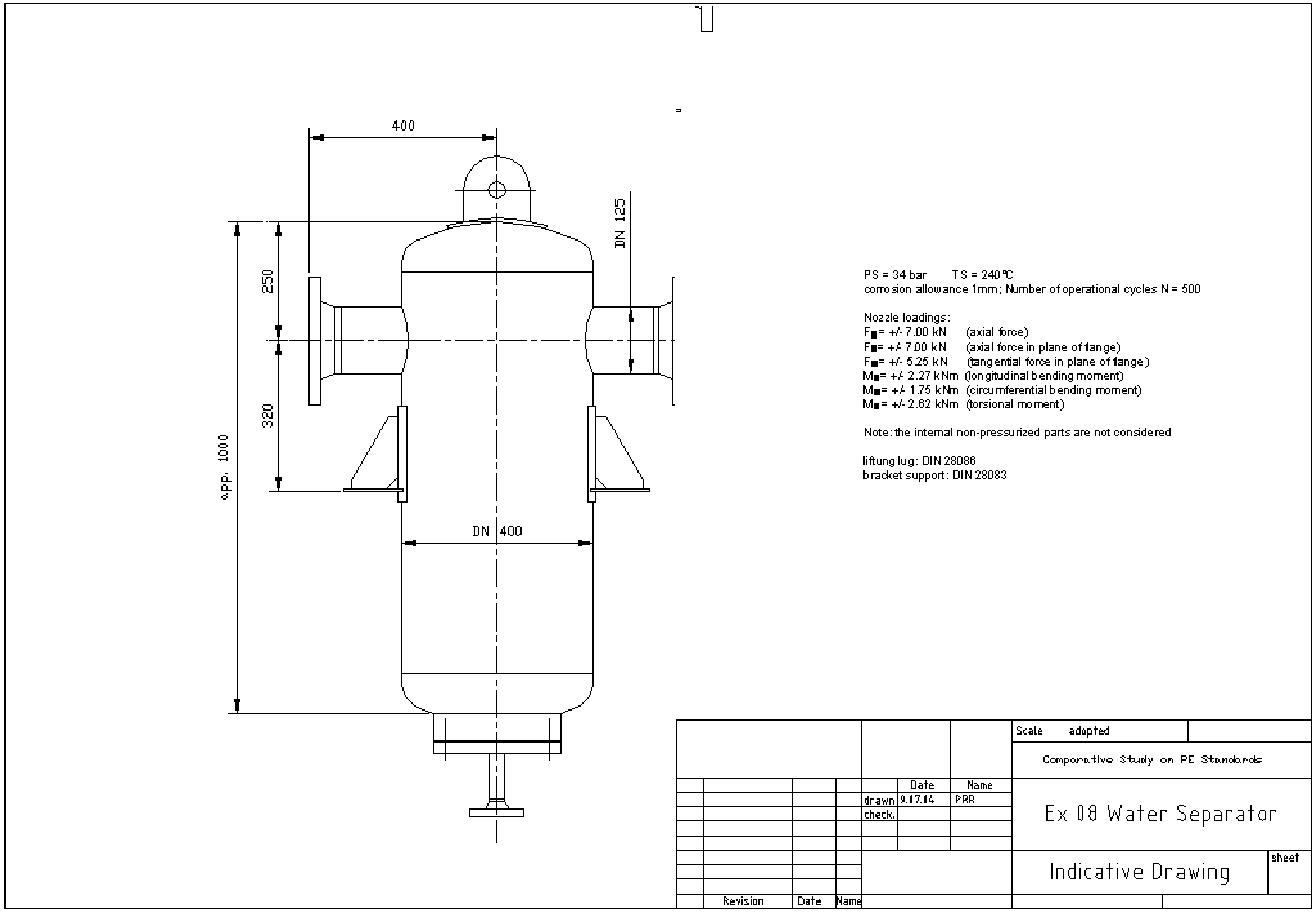
**Comparision of Results: Comp. Study EX7 (Fixed Tube Heat Exchanger)**

| Part | EN 13345-3 DBF | | | ASME VIII/1 | | | + PED |
|---|---|---|---|---|---|---|---|
| | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference[1] |
| Shell | 3 mm | X5CrNi18-10<br>EN 10028-7 | | 3 mm | SA-240 TP304 | | 3 mm |
| Channel | 3 mm | X5CrNi18-10<br>EN 10028-7 | | 3 mm | SA-240 TP304 | | 3 mm |
| Flange | 26 mm | X5CrNi18-10<br>EN 10222-5 | | 28 mm | SA-336 F304 L.S | | 28 mm |
| Tubesheet | 11 mm | X5CrNi18-10<br>EN 10028-7 | | 10 mm | SA-240 TP304 | | 10 mm |
| Cover | 26 mm | X5CrNi18-10<br>EN 10028-7 | | 28 mm | SA-240 TP304 | | 28 mm |

Fatigue analysis according to EN 13445-3 Annex J.10; Fatigue analysis not required by ASME VIII div. 2 AD-160.2.

[1] based upon the test pressure required by the PED

## Example 8 Water Separator: Indicative drawing



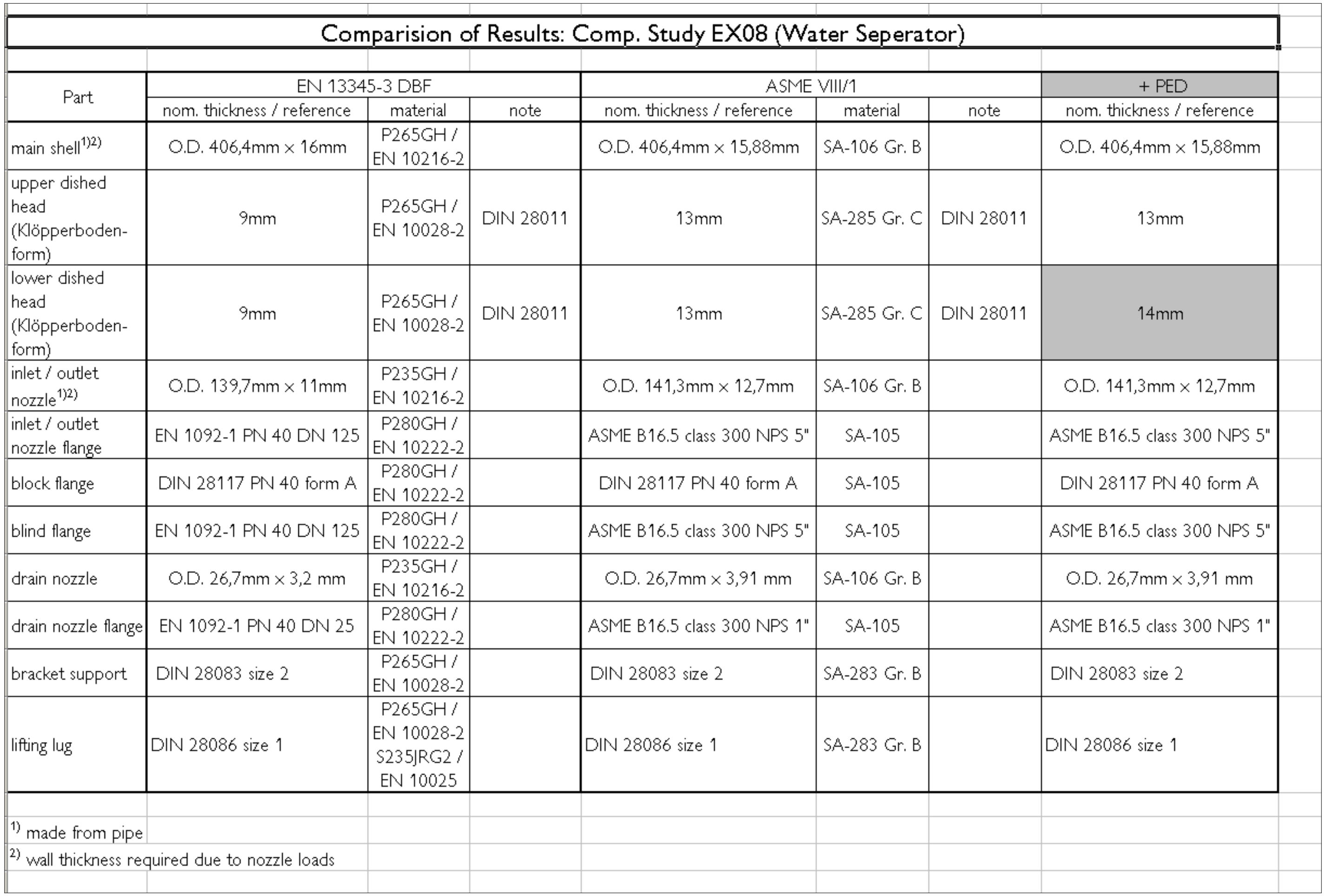
PS = 34 bar TS = 240°C
corrosion allowance 1mm; Number of operational cycles N = 500

Nozzle loadings:
F■ = +/- 7.00 kN (axial force)
F■ = +/- 7.00 kN (axial force in plane of flange)
F■ = +/- 5.25 kN (tangential force in plane of flange)
M■ = +/- 2.27 kNm (longitudinal bending moment)
M■ = +/- 1.75 kNm (circumferential bending moment)
M■ = +/- 2.62 kNm (torsional moment)

Note: the internal non-pressurized parts are not considered

liftung lug: DIN 28086
bracket support: DIN 28083

Example 8 Water Separator: Comparison of Results Sheet



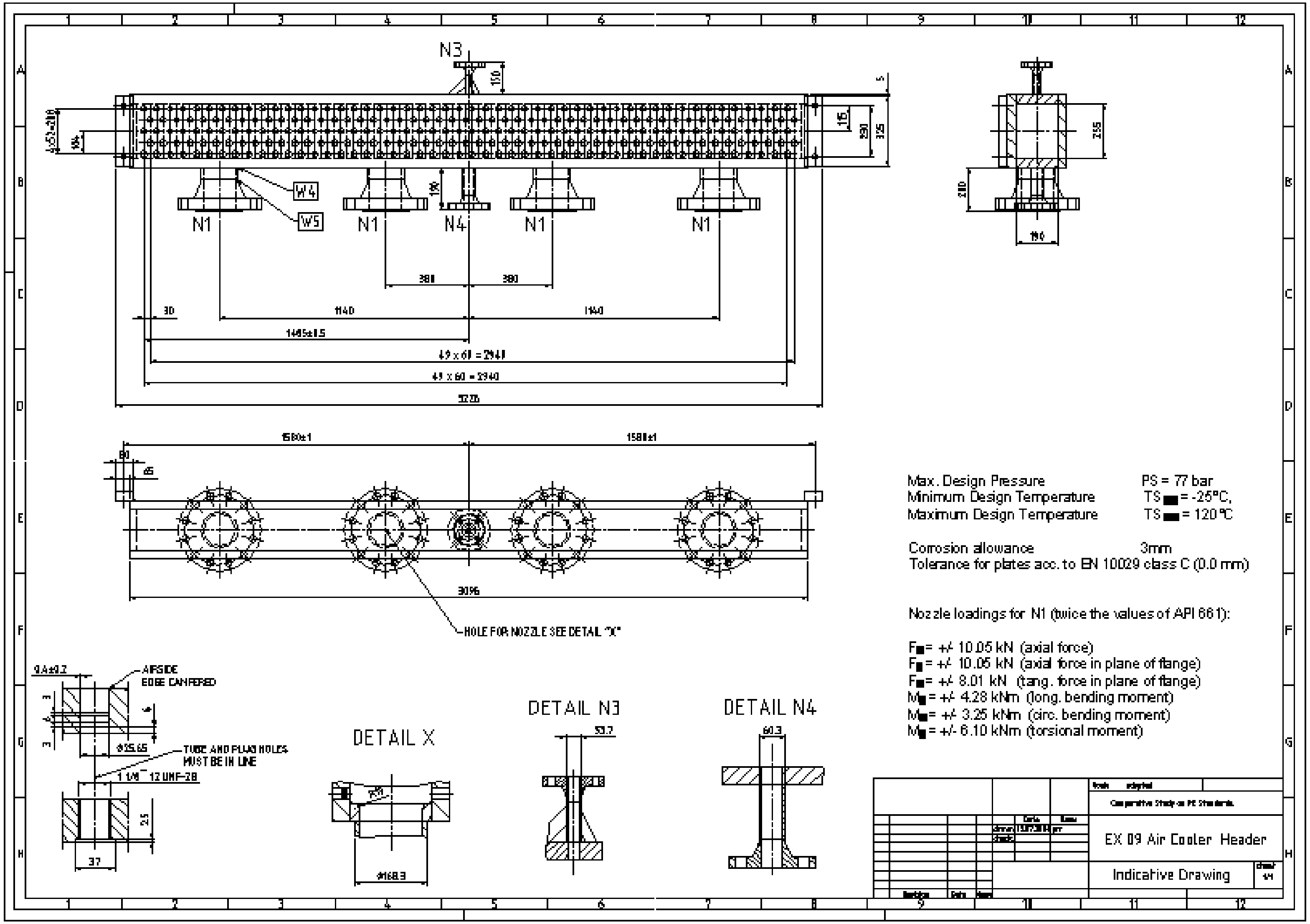
## Comparision of Results: Comp. Study EX08 (Water Seperator)

| Part | EN 13345-3 DBF | | | ASME VIII/1 | | | + PED |
|---|---|---|---|---|---|---|---|
| | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference |
| main shell 1)2) | O.D. 406,4mm × 16mm | P265GH / EN 10216-2 | | O.D. 406,4mm × 15,88mm | SA-106 Gr. B | | O.D. 406,4mm × 15,88mm |
| upper dished head (Klöpperboden-form) | 9mm | P265GH / EN 10028-2 | DIN 28011 | 13mm | SA-285 Gr. C | DIN 28011 | 13mm |
| lower dished head (Klöpperboden-form) | 9mm | P265GH / EN 10028-2 | DIN 28011 | 13mm | SA-285 Gr. C | DIN 28011 | 14mm |
| inlet / outlet nozzle 1)2) | O.D. 139,7mm × 11mm | P235GH / EN 10216-2 | | O.D. 141,3mm × 12,7mm | SA-106 Gr. B | | O.D. 141,3mm × 12,7mm |
| inlet / outlet nozzle flange | EN 1092-1 PN 40 DN 125 | P280GH / EN 10222-2 | | ASME B16.5 class 300 NPS 5" | SA-105 | | ASME B16.5 class 300 NPS 5" |
| block flange | DIN 28117 PN 40 form A | P280GH / EN 10222-2 | | DIN 28117 PN 40 form A | SA-105 | | DIN 28117 PN 40 form A |
| blind flange | EN 1092-1 PN 40 DN 125 | P280GH / EN 10222-2 | | ASME B16.5 class 300 NPS 5" | SA-105 | | ASME B16.5 class 300 NPS 5" |
| drain nozzle | O.D. 26,7mm × 3,2 mm | P235GH / EN 10216-2 | | O.D. 26,7mm × 3,91 mm | SA-106 Gr. B | | O.D. 26,7mm × 3,91 mm |
| drain nozzle flange | EN 1092-1 PN 40 DN 25 | P280GH / EN 10222-2 | | ASME B16.5 class 300 NPS 1" | SA-105 | | ASME B16.5 class 300 NPS 1" |
| bracket support | DIN 28083 size 2 | P265GH / EN 10028-2 | | DIN 28083 size 2 | SA-283 Gr. B | | DIN 28083 size 2 |
| lifting lug | DIN 28086 size 1 | P265GH / EN 10028-2<br>S235JRG2 / EN 10025 | | DIN 28086 size 1 | SA-283 Gr. B | | DIN 28086 size 1 |

1) made from pipe

2) wall thickness required due to nozzle loads

# Example 9 Air Cooler: Indicative drawing



Max. Design Pressure PS = 77 bar  
Minimum Design Temperature TS■ = -25°C,  
Maximum Design Temperature TS■ = 120 °C

Corrosion allowance 3mm  
Tolerance for plates acc. to EN 10029 class C (0.0 mm)

Nozzle loadings for N1 (twice the values of API 661):

F■ = +/- 10.05 kN (axial force)  
F■ = +/- 10.05 kN (axial force in plane of flange)  
F■ = +/- 8.01 kN (tang. force in plane of flange)  
M■ = +/- 4.28 kNm (long. bending moment)  
M■ = +/- 3.25 kNm (circ. bending moment)  
M■ = +/- 6.10 kNm (torsional moment)

Example 9 Air Cooler: Comparison of Results Sheet

## Comparison of Results: Comp. Study EX09 (Air Cooler Header)[A]

| Part | EN 13345-3 DBF | | | EN 13445-3 Annex B DBA [1][2][3] | | | ASME VIII/1[C] | | | + PED[C], [4] | ASME VIII/2 [B] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference | material | note | nom. thickness / reference | nom. thickness / reference | material | note |
| tube plate | 40mm | P 355 NL1<br>EN 10028-3 | | 34mm | P 355 NL1<br>EN 10028-3 | | 46 mm | SA-738, Gr.B | | 47mm | | | |
| plug plate | 40mm | P 355 NL1<br>EN 10028-3 | | 34mm | P 355 NL1<br>EN 10028-3 | | 46 mm | SA-738, Gr.B | | 47mm | | | |
| side wall | 40mm | P 355 NL1<br>EN 10028-3 | | 34mm | P 355 NL1<br>EN 10028-3 | | 43 mm | SA-738, Gr.B | | 43mm | | | |
| end plate | 28mm | P 355 NL1<br>EN 10028-3 | | 19mm | P 355 NL1<br>EN 10028-3 | | 29 mm | SA-738, Gr.B | | 30mm | | | |
| nozzle branch (N1) | 168.3*11 mm | P 255 QL<br>EN 10216-4 | | 168.3*11 mm | P 255 QL<br>EN 10216-4 | | NPS 6, 0.719 in | SA-333, Gr. 1 | | NPS 6, 0.719 in | | | |
| flange (N1) | DN 150, class 900<br>prEN 1795-1 | P 355 QH1<br>EN 10222-4 | acc. to rating<br>EN 1795-1 | DN 150, class 900<br>prEN 1795-1 | P 355 QH1<br>EN 10222-4 | acc. to rating<br>EN 1795-1 | NPS 6, class 900 | SA-350,<br>Gr. LF6 | acc. to rating<br>ASME B 16.5 | NPS 6, class 900 | | | |
| nozzle branch (N4) | 60.3*6.3 | P 255 QL<br>EN 10216-4 | | 60.3*6.3 | P 255 QL<br>EN 10216-4 | | NPS 2, 0.281 in | SA-333, Gr. 1 | | NPS 2, 0.281 in | | | |
| flange (N4) | DN 50, PN 100<br>EN 1092-1 | P 355 QH1<br>EN 10222-4 | acc. to rating<br>EN 1092-1 | DN 50, PN 100<br>EN 1092-1 | P 355 QH1<br>EN 10222-4 | acc. to rating<br>EN 1092-1 | NPS 2, class 600 | SA-350,<br>Gr. LF6 | acc. to rating<br>ASME B 16.5 | NPS 2, class 600 | | | |
| nozzle branch (N3) | 33.7*5 | P 255 QL<br>EN 10216-4 | | 33.7*5 | P 255 QL<br>EN 10216-4 | | NPS 1, 0.25 in | SA-333, Gr. 1 | | NPS 1, 0.25 in | | | |
| flange (N3) | DN 25, PN 100<br>EN 1092-1 | P 355 QH1<br>EN 10222-4 | acc. to rating<br>EN 1092-1 | DN 25, PN 100<br>EN 1092-1 | P 355 QH1<br>EN 10222-4 | acc. to rating<br>EN 1092-1 | NPS 1, class 600 | SA-350,<br>Gr. LF6 | acc. to rating<br>ASME B 16.5 | NPS 1, class 600 | | | |

[A] Formerly, the usage of ASME VIII Div. 1 is not possible since no hint is given concerning the analysis of nozzle loads for the geometry considered. Thus, usage of ASME VIII Div. 2 Appendix 4 would be a basic possibility but as stated in [B] below the vessel cannot be built under these rules.

[B] ASME VIII/2 is not applicable because of the required corner joint weld geometry.

[C] According to Appendix 28 of ASME VIII Div. 1

[1] PD check ok

[2] Fatigue analysis ok

[3] The parts 5 to 10 are not designed via DBA

[4] Increased wall thicknesses required due to the minimum test pressure according to the PED

Mill tolerances of plates according to EN 10029 class C.