APPROPRIATE USE OF TITANIUM FOR CHEMICAL EQUIPMENT DESIGN

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Summary

Versatility of Titanium is all too frequently overlooked because process and mechanical designers fail to design processes and equipment prudently using material.

Too often heat exchangers are first oversized and secondly use heavier gauge tubing and plate materials than required.

In vessels Detaclad material is used when solid Titanium would be appropriate and less expensive. In turn, solid Titanium is sometimes specified when conditions warrant a less expensive loose liner construction.

Proper use of reinforcing rings is too often disregarded in vessel design. The extra material costs thus incurred can result in other less desirable materials being substituted for Titanium.

Proper heat exchanger, reactor and column design can be accomplished by using commonly available design criteria and common sense. Heat exchanger surface area can and should be optimally designed. Similarly, reactors and various mass transfer columns can and should be designed to minimize wall thickness or minimal use of Titanium while providing required contact time and suitable length over diameter ratios.

One of the most important considerations in appropriate use of Titanium is energy conservation. Many Titanium heaters and coolers can be replaced with all Titanium interchangers with almost amazing payouts and long term dollar and BTU (British Thermal Units) savings.

APPROPRIATE USE OF TITANIUM FOR CHEMICAL EQUIPMENT DESIGN

In the late 1950's Titanium began to move out of the exotic aerospace material classification. Commercial and particularly chemical interests started stirring. Unfortunately, early designs tended to look at the material as another metal and automatically applied a number of rule of thumb "safety" factors beyond Code requirements normally used for less expensive materials. For example, substantial corrosion allowances would be added to vessel design specifications.

By 1970, more intelligent use of material was taking place. Thinner gauges gained more acceptance, corrosion allowances used less frequently and design standards outside the ASME Code such as TEMA not always strictly observed.

However, even today imagination and innovative use of material is too often overlooked. Obviously with the ever increasing cost of Titanium, smarter material use is more necessary than ever. The alternate will be increased use of less expensive and less suitable substitute materials - a giant step backwards for both Titanium producers and users.

Heat Exchangers

There are a number of factors in shell and tube heat exchanger design affecting the amount of Titanium needed for a specific unit.

First, tubing specifications still all too often call for 18 BWG. Eighteen (18) BWG costs approximately 50% more than 20 BWG. Twenty (20) BWG does have wide acceptance and has proved its reliability. But 22 BWG tubing has also proved its worth and is approximately 25% less expensive than 20 BWG. Unfortunately, chemical producers rarely if ever specify or accept 22 BWG.

The Chemical Process Industries would do well to take a lesson from the Power Industry. The Power Industry has been successfully using 22 BWG tubing for several years. They also do not use the relatively conservative design approach the Chemical Process Industries (CPI) does.

The Power Industry usually design their heat exchanger equipment for actual conditions and on a clean service basis. If additional capacity or a "safety factor" is to be incorporated in design they allow for a modest extra percentage in surface area - say 10%.

On the other hand, the Chemical Process Industries design on the basis of the worst possible process conditions and cling to the fouling factor concept with zealous tenacity.

As an example of the worst possible process condition many CPI companies will specify 85° F cooling water when this condition might exist no more than two or three days in an entire year. Scheduled shut downs and plant maintenance problems cost far more capacity loss than could ever be anticipated by operating for a few hours at conditions in excess of design.

Table I has been prepared to demonstrate the dramatic effect the use of arbitrary fouling factors has on equipment size.

Table I

Effect of Fouling Factor on Heat Exchanger Surface Area Specifications

Overall Heat Transfer Rate Clean (U_C)	Overall Fouling Factor (ff)	Overall Heat Transfer Rate Design (U_D)	% "Extra" Area
500	0.003	200	150
400		182	120
300		158	90
100		77	30
500	0.002	250	100
400		222	80
300		188	60
100		83	20
500	0.001	333	50
400		286	40
300		231	30
100		91	10

Note then the better the heat transfer rate the more significant a fouling factor becomes. A clean rate of 500 BTU/HR° F sq·ft (ft^2) with a 0.003 fouling factor requires 150% excess surface area to meet specification. Since the cooling water temperature has probably been specified 10° F or more higher than realistic we have an additional significant surplus surface area.

If on a clean basis 1000 square feet of surface area is required, a 0.003 fouling factor results in 2500 square feet being specified. At say $25.00/ square foot a $62,500.00 heat exchanger is doing the work a $25,000.00 unit could.

Mechanical design of heat exchangers is another area of significant waste. Fixed tube sheet design is satisfactory for up to 90% of the CPI applications. Yet many times companies will specify floating head construction adding up to 25% to the heat exchanger cost.

In fixed tube sheet design a few users still specify solid Titanium tube sheets. This is ridiculous at best.

since Titanium cannot be welded to steel, solid tube sheet construction requires an irreplaceable gasket between the tube sheet and the steel shell flange. Titanium fabricators have made a lot of money over the years remodeling or replacing these design monstrosities with Titanium faced tube sheets.

Even faced tube sheets provide a cost bone of contention. Many users prefer Titanium Detaclad steel tube sheets over Titanium lined construction. Both designs are more than adequate for the requirements but Detaclad will add 5 to 10% to the unit cost. Detaclad is a fine material and in itself a good example of appropriate use of material. However, for heat exchanger tube sheets it provides an unnecessary extra cost.

Arbitrary adherence to Association Standards often require excessive use of premium material. Significant savings can often be realized if strict following of TEMA standards is avoided. In many cases channel walls can be designed in accord with ASME pressure vessel code and be thinner than TEMA minimum specifications. The same is true of baffle thicknesses. While there is nothing technically wrong with designing a heat exchanger in accord with say TEMA R standards, it does add unnecessary cost.

Fortunately, corrosion allowances on Titanium have almost been abandoned. Titanium in suitable service is virtually immune to corrosion. Hence, corrosion allowances become unnecessary and if used, expensive.

Vessels

Process vessel design should always evaluate solid material, Detaclad and lined construction. Figure I shows such an evaluation of the straight tan. to tan. section for a 6' diameter, 10' long unit designed for 75 PSIG at 300° F.

Comparison of Solid
Titanium Vessel Costs
Versus Loose Lined
or Detaclad

Vessel 6' Dia. x 10' tangent-tangent

Design Temperature	300° F
Design Pressure	75 PSIG

Figure I

Fabricated Wrapper Cost Summary

Solid Titanium

$$t = \frac{PRO}{SE+0.4P}$$

$$t = \frac{36 \times 75}{9000+0.4(75)} = 0.299''$$

use 3/8" Nominal (0.375")

$$WT = 72\pi \times 120 \times 0.375 \times 0.163 = 1658\#$$

$$Cost = 1658 \times 8 = \$13{,}264.$$

Titanium Detaclad Steel

$$t = \frac{36 \times 75}{17500+0.4(75)} = 0.154''$$

minimum steel thickness per Supplier 11/16"

$$WT = 72\pi \times 120 \times 0.6875 \times 0.28 = 5225\#$$

$$Cost = 5225 \times 3 = \$15{,}675.$$

Titanium Loose Lined Steel

$$t = \frac{36 \times 75}{17500+0.4(75)} = 0.154''$$

use 1/4" Nominal (0.25")

$$WT_{Stl.} = 72\pi \times 120 \times 0.25 \times 0.28 = 1900\#$$

$$WT_{Liner} = 72\pi \times 120 \times 0.083 \times 0.163 = 367\#$$

$Cost_{Stl.} = 1900 \times 0.30 = 570$

$Cost_{Ti.} = 367 \times 8 = 2936$

Labor Increment = 5000 (over solid Ti)

Total Cost $8506

Cost Summary

Titanium Loose Lined Steel (including extra labor)	$ 8,506
Solid Titanium	13,264
Titanium Detaclad (not including extra labor)	15,675

In this case, the loose lined construction would appear to be the least expensive. To be completely accurate the same comparison must be made on heads, nozzles, and internals if any.

At current Titanium prices lined vessels are probably the best buy if solid thickness is greater than 1/8". An exception would be for vessels designed for vacuum service. The additional material and labor required to provide liner vacuum supports often offsets the additional material cost of a solid unit.

On the other hand, external reinforcing rings on solid vessels designed for positive pressure will often reduce gross material requirements substantially more than the effect of additional labor costs.

Nozzle reinforcing can be another significant cost factor. Sometimes using heavier wall material eliminates the need for nozzle reinforcement and can produce an optimum cost unit.

In any event, both lined and solid construction should always be evaluated to determine the best cost and appropriate use of material.

Detaclad material is always a candidate for vessels operating at higher pressures. When vessel wall thicknesses reach 3/4", Detaclad construction becomes a real contender for most appropriate use of material.

When design pressure and temperature in conjunction with vessel diameter require thick wall solid material, Detaclad can cut costs as much as 50%.

As in heat exchanger design, vessel designers should avoid unnecessary safety factors and additional (extra) capacity considerations. Determine required capacity and mechanically design accordingly.

In distillation or absorption column design actual requirements should only be considered. The old "we need ten trays but they will work at about 50% efficiency so let's put in 20" should be discarded for more accurate design procedures. With the availability of computer hard and software, accurate mass transfer calculations are not the drudgery they were with slide rules.

Pressure drop and loading characteristics should be evaluated carefully so as not to increase vessel diameters needlessly.

Reactors

Reactors are obviously in the general category of vessels. However, the process design of a reactor often involves complex kinetic calculations to arrive at the proper sized unit. Determination of reaction order and reaction rates is necessary to compute residence time which in turn determines reactor volume.

Once reactor volume is determined for specific design conditions an economic evaluation of vessel(s) geometry should be done. In general the greater the length over diameter ratio the more efficient the reactor will operate. Minimum ratios of 6:1 are not uncommon.

Particularly with large volume and high pressure (500 cu. ft. or more and pressures over 500 PSIG) creative design can make appropriate use of material. Instead of one large reactor, reactors containing two or more vessels in series should be cost evaluated. Generally a modest reduction in gross material will result from multistage reactor configuration.

More importantly, reduced diameter will improve reactor overall efficiency (in effect increasing overall L/D ratios) with better hydraulic and mixing characteristics. Also, thinner wall vessels can be used with smaller diameters. This will help cut forming and fabrication costs. Expensive internals and/or agitation equipment could conceivably be eliminated in some cases.

All of which leads to appropriate use of material and optimum equipment cost.

Piping

Piping is one area where appropriate use of material is best practiced today. Seamless pipe is available in up to 6" diameters in strict accord with B337 specifications. For larger diameters welded piping is frequently fabricated in accord with ASME pressure vessel codes eliminating some redundant testing requirements. For example, B337 calls for piping to be hydrostatically tested. If fabricated pipe is to be hydrostatically tested as part of an assembly, why duplicate the test?

The only concern with piping is that it be properly designated as to fabricated or B337 specifications.

While piping is an example of practicing good material application, over specification is always a hazard. Too often schedule 40 is specified when schedule 10 is adequate or schedule 10 specified when schedule 5 is okay. Carelessness in specifying can be expensive.

Radiography

Too long now the Titanium industry has been held to 100% radiography for Code vessel fabrication. Titanium is over due to graduate as stainless steel did from the 100% x-ray requirement to spot x-ray.

Quality control (QC) is necessary and expensive. However, unnecessary QC is an added burden that should be eliminated. With the amount of welding data generated in the past 20 years, the American Society of Mechanical Engineers would welcome a joint industry effort to set this needless QC requirement aside.

Energy Conservation

While not in the strictest sense an example of appropriate material use, conservation of energy by using proper materials is a most important consideration.

In the chlorine industry alone hundreds of millions of BTU's are being needlessly wasted every day. A major portion of this energy is spent preheating brine for cell feed. This energy and the heat generated in the cell itself is in most cases dissipated - thrown away.

A large portion of brine preheating can be accomplished by using heat interchangers to cool chlorine gas and spent brine with the cold brine feed. Cooling water consumption is also greatly reduced. It has been done in some isolated cases.

Installation of Titanium heat interchange equipment in chlorine plants would have a 12 to 18 months payout with ongoing long term significant energy cost savings.

I said maybe energy conservation was not in the strictest sense a good example of appropriate material use. On second thought, it is probably the best example. By proper use of this material a 12 to 18 months payout with substantial ongoing reduction in costly energy input is available. There are not many investments around that good for the simple expediency of using the right material and design.

However, the subject of Titanium's role in energy conservation really deserves to be in its own right the subject of an entire series of papers and actions.

Appropriate use of material is more critical today than ever with almost constant cost and availability pressures. It is incumbent on us to set aside our technical bureaucracy and cease relying on archaic and outmoded, if comfortable, design procedures. We have the tools to design properly. There is no excuse to do otherwise. In fact, to do otherwise can have a serious impact on the continued growth of suitable applications for Titanium.

Explanation of Abbreviation in Figure I (page 4, 5)

t .... Thickness in inches.

p .... Design pressure in PSIG(Pounds per square inch gage).

RO .... Outside Radius of vessel in inches.

s .... Allowable design stress pounds per square inch as defined in ASME Code.

E .... Efficiency (Titanium efficiency is generally 1.0, because all weld joints are x-rayed).

WT .... Weight in pounds.