Ferritic stainless steel (K39 and K44) for the sugar industry and distilleries

Bruno Meyer

Aperam Stainless Services and Solutions Tubes Europe, 1 rue de Prêle 55170 Ancerville, France; bruno.meyer@aperam.com

Abstract Co-generation is more and more important for sugar plants but without increasing the consumption of steam. A research overview concerning the best material and surface aspects for tubes in evaporators, heaters and vacuum pans of sugar mills and distilleries is given. The difference in roughness between the internal and external surface of ferritic tubes solves these problems. The inside roughness must be very low to limit scaling but is more important on the outside to break the water film. Several cane and beet sugar processing plants were studied to analyse production conditions. Using tubes of ferritic grade, we could meet an energy gain of about 10%. The main considerations in the selection of tube materials are corrosion resistance and its effect on the durability of the tube, mechanical strength and its effect on the structure of the heat exchanger, thermal conductivity and its effect on the amount of energy of steam required, and surface finish and its effect on scaling and cleaning.

Key words Stainless steel, ferritic, tubes, heat exchanger, energy savings, K39, K44

INTRODUCTION

Current major requirements in a sugar-processing plant are to reduce the amount of energy consumption and to use a part of this saving to produce electricity. One of the main processes in a sugar plant is evaporation that removes water from the juice. This system uses much energy and involves heat transfer through tubes providing heat-transfer areas amounting to tens of thousands of square meters. The price of tubes directly affects the equipment-cost factor, while the quality of the installed tubes affects energy consumption.

Tubes are used for many heat exchanger applications in a sugar factory especially in heaters and evaporators. Figure 1 shows the conditions of use of a tube in a heat exchanger and the key factors impacting on it.

![Fig. 1. Tubular heat exchanger tube.](image)

The aim of this study was to find a solution that would give the best possible heat-exchange performance with a tube of the most suitable steel grade in terms of corrosion resistance, durability and price.
KEY FACTORS

Key factors are:
1. The thickness of the condensate and juice (film) on the tubes
2. The wall thickness of the tubes
3. The thickness of the scale (variable during the season)
4. The thermal conductivity of the material
5. The corrosion resistance of the tube

Each of these is discussed below.

Condensation and water film - This factor is difficult to improve. By its nature, heat transfer creates considerable condensation. To limit the thickness of the water film on the external surface of the tube, the roughness will cause the water film to have a better contact between steam and the stainless steel.

Tube thickness - With the grade K39 (AISI439), the most used thicknesses are usually in a range of 1.2-1.5 mm for evaporators and 1.5-2 mm for vacuum pans. Reducing this range of thickness, considering the length of the calandria of the evaporators and without an increase in length of the heat exchangers, is usually difficult.

Scaling thickness - Scale accumulation can have various causes:
- The surface finish of the tube’s internal wall In contrast to the external surface, the roughness of the internal surface of the tube is limited to around 0.4 µm using the specific manufacturing tools. It is a major factor in limiting scale accumulation when juice is flowing through a tube.
- The weld surface inside the tube – Manufacturers, usually only for the ferritic grades, use laser welding to ensure a very smooth surface (Fig. 2). This process ensures a highly consistent weld and a small weld-bead to avoid the sticking of tartar.

Fig. 2. Micrograph of a laser weld.

Thermal conductivity - The thermal conductivities of tube materials are for austenitic grade (AISI 304) is 16 W/m K and K39 is 24 W/m K. The conductivity should be as high as possible, to ensure the efficient transfer of heat. The higher this factor is, the lower is the requirement of heating surface area.

Corrosion resistance - The corrosion resistance of the ferritic grades is more efficient than standard austenitic grades due to the absence of stress corrosion (Tables 2 and 3).
THE MOST EFFICIENT SOLUTION

Trantherm tubes in K39 are an alternative solution to standard austenitic tubes with a smooth surface (Fig. 3).

![Diagram showing Classic and Trantherm tube principles](image)

**Fig. 3.** The thermal resistance of the water film is reduced.

PHYSICAL PROPERTIES OF THE MATERIALS

Apart from thermal conductivity requirements, there are other necessary material properties for the evaporator tube application. Tubes:

- Are held to the plates by swaging (require ease of deformation);
- Pass through intermediate plates (require mechanical strength);
- Are subjected to vibration (require mechanical strength);
- Are subjected to chemical attack from sugar juice (require general corrosion resistance);
- Are cleaned by various procedures (require pitting corrosion resistance).

Properties such as the coefficient of linear expansion, strength and corrosion resistance are important. Table 2 and Figure 4 show the physical properties of the different tube materials.

The coefficient of linear expansion has become more important as tubes have become longer. With K39, the tubes bend less at high temperatures although tubes are mechanically terminated at both ends. The lower amount of bending lessens the rubbing of tubes against each other and reduces premature wear in the intermediate plates.
Table 2 – Comparison between AISI 304 and K39 grades (Aperam, 2011, 2015; Isbergues Research Center, 2012).

<table>
<thead>
<tr>
<th>Grade</th>
<th>K39</th>
<th>304</th>
<th>Advantages of ferritic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat treatment</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Thickness mm</td>
<td>1.2 to 1.5</td>
<td>1.2 to 1.5</td>
<td>1.2 to 1.5</td>
</tr>
<tr>
<td>Density kg/dm³</td>
<td>7.73</td>
<td>7.93</td>
<td>7.93</td>
</tr>
<tr>
<td>Rm Mpa</td>
<td>450</td>
<td>720</td>
<td>600</td>
</tr>
<tr>
<td>Rp0.2% Mpa</td>
<td>370</td>
<td>570</td>
<td>320</td>
</tr>
<tr>
<td>A%</td>
<td>40</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Linear elongation m10⁻⁶/°C</td>
<td>9.8</td>
<td>16.1</td>
<td>16.1</td>
</tr>
<tr>
<td>Expanding operation</td>
<td>+++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Thermal conductivity W/m/°K</td>
<td>24</td>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

Corrosion resistance: 0 = bad / 100 = very good

Grade K39 Family ferritic Heat treatment NO NO YES Thickness mm 1.2 to 1.5 1.2 to 1.5 1.2 to 1.5 Density kg/dm³ 7.73 7.93 7.93 Rm Mpa 450 720 600 Rp0.2% Mpa 370 570 320 A% % 40 50 55 Linear elongation m10⁻⁶/°C 9.8 16.1 16.1 Expanding operation +++ ++ ++ Thermal conductivity W/m/°K 24 16 16

Fig. 4. Specific comparison between 304 and K39 steel grades.

MECHANICAL PROPERTIES

The mechanical properties are very important for the setting and the stability of the structure. The yield strength of K39 is close to the plates made in carbon steel what results in ease for swaging. The mechanical characteristics of K39 allow reducing the thicknesses (reduction of weight).

Corrosion

The corrosion properties of tube materials are also shown in Tables 2 and 3. They are rated with a scale from 0 (poor resistance) to 100 (good resistance), based on theoretical and real measurement on the material. Tubes in K39 are only produced, not annealed and without additional treatment; contrary to austenitic grades.
Why not annealed tubes in K39?

- Yield strength at 20°C of K39 not annealed tubes equals to austenitic annealed tubes;
- Absence of stress corrosion;
- Best mechanical properties (Table 2);
- Lower price for not annealed tubes compared to annealed ones;
- Contrary to K39 tubes, austenitic tubes need an annealing to improve the stress corrosion resistance.

Cleaning recommendations for K39

This grade is adapted to different processes of cleaning according to procedures reflecting its chromium content. The best practice is to use a caustic solution with high pressure water or mechanical brushing and avoid acid cleaning that can damage the internal surface of the tubes. Their low surface roughness limits the scaling (Ra <0.4 µm).

Tube life

Since 1974, these tubes have been installed in many cane and beet sugar refineries in Europe and on all the continents. Their expected service life is about 25 years in evaporators and 35 years in vacuum pans. They have been used in: evaporators: USA (US Sugar), Guadeloupe (Gardel), Morocco (Cosumar), Colombia (Providencia), Sudan (White Nile), Réunion (Bois-Rouge), Guatemala (Palo Gordo), Sénégal (CSS); and vacuum pans : Mauritius (Fives), Costa Rica (El Viejo), Africa (Mercier, Delta Sugar), Mexico (Ingeniería y equipos Cail), Thailand (Mitr Phu), Philippines (Cotabato).

Financial factors

The absence of nickel in K39 chemical composition means that this grade is much less affected by speculation on the global financial markets. Consequently, it’s possible to:

- Offer a lower price than 304 (which contains at the minimum 8% Ni);
- Offer longer price-validity periods, thanks to the relative stability of the chromium price.

Distillery application requirements

The basic needs are identical to the sugar application but with a focus on the corrosion resistance. The same analysis was performed for K44 (AISI 444) but by taking as basic grade AISI 316L (Table 3, Fig. 6).
**Table 3.** Comparison between 316L and K44.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>316L</td>
</tr>
<tr>
<td>Family</td>
<td></td>
<td>austenitic</td>
</tr>
<tr>
<td>Fabrication</td>
<td></td>
<td>TIG welded</td>
</tr>
<tr>
<td>Annealed</td>
<td></td>
<td>yes</td>
</tr>
<tr>
<td>Thickness</td>
<td>mm</td>
<td>1.2 to 2</td>
</tr>
<tr>
<td>Density</td>
<td>kg/dm³</td>
<td>7.93</td>
</tr>
<tr>
<td>Rm (tensile strength)</td>
<td>MPa</td>
<td>600</td>
</tr>
<tr>
<td>Rp 0.2% (yield strength)</td>
<td>MPa</td>
<td>300</td>
</tr>
<tr>
<td>A% (elongation)</td>
<td>%</td>
<td>60</td>
</tr>
<tr>
<td>Linear elongation</td>
<td>mm/100°C</td>
<td>16.7</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>w.m⁻¹.K⁻¹</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Corrosion resistance : 0 = bad 100 = very good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitting corrosion</td>
</tr>
<tr>
<td>General corrosion</td>
</tr>
<tr>
<td>Stress corrosion</td>
</tr>
</tbody>
</table>

**Fig.6.** Specific comparison between 316L and K44.

**Financial factors**

The absence of nickel in the K44 material means that this grade is much less affected by speculation on the global money markets. Consequently, it is possible to:

- Offer a lower price than 316L;
- Offer longer price-validity periods, thanks to the relative stability of the chromium price.
CONCLUSIONS

This study showed how well-positioned the material grades K39 and K44 are in all the following key factors in a sugar and distillery process with special regard to evaporation and pan boiling:

- Thermal conductivity (30% better than an austenitic grade)
- Specific surface finish (roughness)

On ferritic grades, we guarantee 0.4 µm on the internal surface regards the standard value 0.8 µm on austenitic grades which affects the following parameters in a positive way:

- Mechanical properties
- Corrosion resistance
- Life time

The improvement of time life regarding austenitic grades is due to the mechanical properties. The absence of thermal elongation and stress corrosion allows lower costs and maintenance.

REFERENCES

Isbergues Research Center and CNRS. 2012. Study on corrosion resistance of stainless steel.

Aciers inoxydables ferritiques (K39 et K44) pour l'industrie sucrière et distillerie

Résumé. La co-génération étant une activité de plus en plus importante dans les sucreries, la consommation d'énergie devient un paramètre fondamental. Nous présentons ici le résultat de nos recherches montrant le meilleur matériau et aspect de surface pour équiper les évaporateurs, réchauffeurs et cuves dans les sucreries et distilleries. La réponse à cette problématique est la différence de rugosité entre la face interne et externe des tubes en nuance ferritique. La rugosité interne doit être faible pour éviter lesentartrage alors qu'elle doit être plus importante sur la face externe pour casser le film d'eau dû à la condensation. Nous avons analysé les conditions de production dans plusieurs sites utilisant la canne ou la betterave. Un gain énergétique de 10% a été observé avec les tubes en nuance ferritique. Les principaux paramètres pris en considération dans la sélection de la nuance sont la résistance à la corrosion et la durée de vie des tubes, les caractéristiques mécaniques et leur impact sur la structure de l'échangeur, la conductivité thermique et ses effets sur la consommation de vapeur, l'aspect de surface et son effet sur l'entartrage et le nettoyage.

Mots-clés: Aciers inoxydables ferritiques (K39 et K44), tubes, échangeur de chaleur, économie d'énergie

Aceros inoxidadles ferríticos (K39 y K44) para la industria azucarera y distilleria

Resumen. La cogeneración es cada vez más importante para las azucareras, el consumo de energía se convierte en un parámetro fundamental. Presentamos aquí el resultado de nuestras investigaciones que muestran el mejor material y el aspecto de superficie para equipar en los evaporadores, los recalentadores y emborrachadas en las azucareras y las destilerías. La respuesta a esta problemática es la diferencia de rugosidad entre la cara interna y la externa de los tubos ferríticos. La rugosidad interna debe ser baja para evitar la incrustación mientras que debe ser más importante sobre la cara externa para romper la película de agua debido a la condensación. Analizamos las condiciones de producción en varios sitios que utilizan la caña de azúcar o la remolacha. Observamos una ganancia energética de 10% con los tubos en ferrítico. Los principales parámetros tenidos en cuenta en la selección del acero inoxidable son: resistencia a la corrosión y su efecto en la durabilidad del tubo, características mecánicas y su impacto sobre la estructura del intercambiador de calor, conductividad térmica y su efecto sobre el consumo de vapor, acabado superficial y su efecto en incrustación y limpieza.

Palabras clave: Acero inoxidable ferrítico K39 y K44, tubos, intercambiador de calor, ahorro energético