

## FERRITIC STAINLESS STEEL AISI 439 FOR THE SUGAR INDUSTRY

By

B. MEYER

*ArcelorMittal Stainless Tubes Europe*  
[Bruno.meyer@arcelormittal.com](mailto:Bruno.meyer@arcelormittal.com)

**KEYWORDS: 439 stainless Steel, Ferritic, Tubes, Heat Exchanger, Energy Savings.**

### Abstract

THE OBJECTIVE of this technical paper is to identify the best material for tubes in evaporators, heaters and vacuum pans of cane sugar mills. Several cane and beet sugar processing plants were studied to analyse production conditions. The main considerations in the selection of tube materials were corrosion resistance and its effect on the durability of the tube, mechanical strength and its effect of the structure of the heat exchanger, thermal conductivity and its effect on the amount of energy required, surface finish and its effect on scaling and cleaning. Several materials were tested. AISI 439 ferritic stainless steel gave the best results.

### Introduction

Today, major requirements at a sugar processing plant are to reduce equipment and energy costs. One of the main processes at a sugar plant is the evaporation system, which removes water from the cane juice. This system uses a lot of energy, and involves heat-transfer through tubes providing heat-transfer areas amounting to tens of thousands of square metres. The price of tubes directly affects the equipment-cost factor, while the quality of the installed tubes affects energy consumption.

This paper reports on the materials and procedures used for tubes in sugar processing plants all around the world and compares them with AISI 439 produced by Arcelor Mittal.

### Analysis and results

#### The requirement

Figure 1 shows a schematic of a conventional tubular heat exchanger. Shells are usually made of carbon steel, as are the intermediate plates or tube-end plates. The tubes are either expansion-swaged into the plates to ensure mechanical closure and sealing or are held by O-ring seals. In the latter case, tube surface finish is a decisive factor in achieving leak-free sealing.

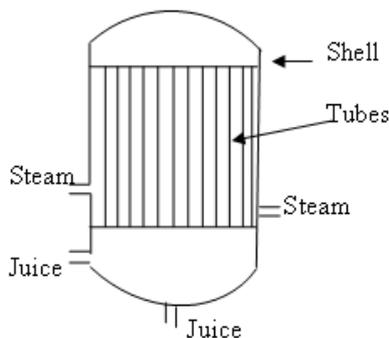


Fig. 1—A tubular heat exchanger.

### Heat flow in a tube

The following equation describes heat transfer through a tube.

$$R = e / \lambda * S$$

where  $\lambda$  is thermal conductivity, S is heat transfer area and e is thickness.

To achieve the best thermal flow, there must be the best possible conductivity. The determining factors are:

- the film of water on the tubes (condensation)
- the thickness of the tubes
- the thickness of the scale (variable during the season)
- the conductivity of the material ( $\lambda$ )

### How can these factors be improved?

#### *Condensation*

This factor is difficult to reduce. By its very nature, heat transfer creates considerable condensation.

#### *Tube thickness*

Currently, thickness is usually from 1.5 to 2 mm depending on the material used. With ferritic grades of stainless steel, thicknesses are from 1.2 to 1.5 mm (depending on the length of the infrastructure of the evaporators) and from 1.5 to 2 mm for boilers.

#### *Scaling thickness*

Scale accumulation can have various causes:

##### *The surface finish of the tube's internal wall*

Limiting the roughness of the internal surface of the tube to around 0.4  $\mu\text{m}$  is a major factor in limiting scale accumulation when juice is flowing through a tube.

##### *The weld surface inside the tube*

Depending on the process used, there may be variable weld-bead build up and consequent variable surface smoothness.

For heat exchanger applications, ArcelorMittal uses laser welding for AISI 439 stainless steel (Figure 2), which ensures a highly consistent weld and a very smooth surface.



Fig. 2—Micrography of a laser weld.

## Grade selection factors

### The chemical composition of stainless steels

Table 1 compares two materials used in evaporator tubes.

**Table 1**—Chemical composition of AISI 304 and AISI 439.

	Stainless steel family	Norms	C%	Ni%	Cr%	Ti%	N%
AISI 439	Ferritic	AISI 439/1. 4510	0.020		17.5–18.5	0.5 max	0.010
AISI 304	Austenitic	AISI 304/1.4307	0.045	8–9	18–19		

### Thermal conductivity

Table 2 shows the thermal conductivity of four tube materials. This parameter should be as high as possible, to ensure the least loss of heat. The higher this factor, the less the process consumes energy and the lower are the production costs. Copper seems the obvious choice but its price and the thicknesses used are a handicap. Carbon steel, which has been very widely used in the past, is now used less because of its poor corrosion resistance and the consequent need for thick gauges. Also, its rough surface finish encourages scaling. Austenitic stainless steels have poor thermal conductivity. AISI 439 ferritic stainless steel is the best technical and financial compromise.

**Table 2**—Thermal conductivity levels for commonly-used materials.

Materials	Thermal conductivity (W/m.°C)
Carbon steel	51
Copper	330
Austenitic stainless steel (AISI 304)	16
Ferritic stainless steel (AISI 439)	24

### The physical properties of the materials:

Apart from thermal conductivity requirements, there are other material properties necessary 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 corrosion resistance)
- are cleaned by various procedures (require corrosion resistance)

Properties such as the coefficient of linear expansion, strength and corrosion resistance are important. Table 3 presents the physical properties of four different tube materials.

The coefficient of linear expansion has become more important as tubes have become longer. With grade AISI 439, the tubes stay straight at high temperature although tubes are mechanically terminated at both ends.

The absence of bending lessens the rubbing of tubes against each other and reduces premature wear in the intermediate-plate area.

The mechanical properties of AISI 439 are more favourable than those of carbon steel, allowing thinner gauges (i.e. reduced weight) and improved heat flow. In addition, AISI 439 shows excellent stability within the usual operational temperatures (Figure 3).

It can be seen that the mechanical characteristics are relatively stable at temperatures found in sugar processing (up to 200°C).

**Table 3**—Comparison of different grades (ArcelorMittal, 1993).

Parameters	Grades			
	439	304	Copper	Carbon steel
	Density			
Density	7.70	7.92	8.94	7.82
	Mechanical properties			
Young's modulus	20 800	20 300	12 500	20 600
Tensile strength (MPa)	450	600	180	380
Yield strength (MPa)	370	350	60	335
Elongation (%)	40	50	35	35
Hardness (HRB)	83	82	41	65
	Linear expansion parameters			
Linear expansion ( $10^{-6}/^{\circ}\text{C}$ )	9.8	16.1	17.6	11.3
	Corrosion resistance: 0 = bad / 100 = very good			
Pitting corrosion	80	80	95	20
Generalised corrosion	100	100	100	60
Stress corrosion cracking	100	20	20	100

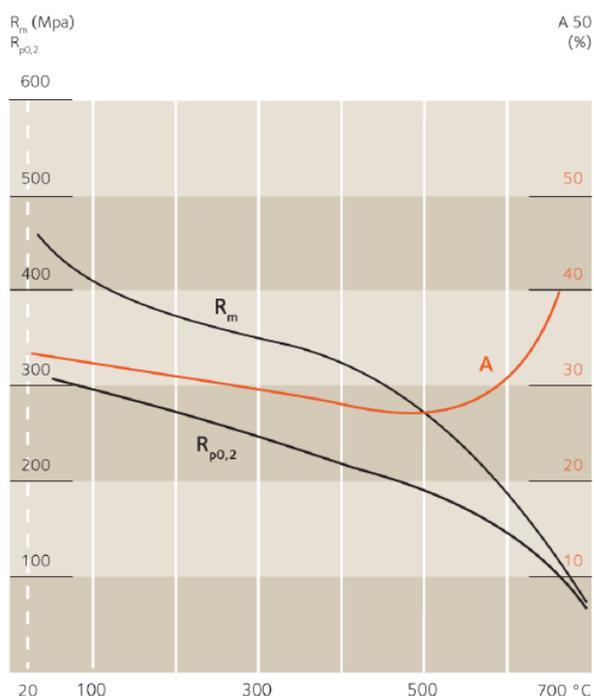


Fig 3—Changes in mechanical characteristics of grade AISI 439 depending on temperature (ArcelorMittal, 2009).

### Corrosion

The corrosion properties of four tube materials are also shown in Table 3. The corrosion properties were rated by ArcelorMittal with a scale from 0 (poor corrosion resistance) to 100 (good resistance), based on the performance of the different materials in corrosion tests.

With the grade AISI 439, the corrosion resistance level is very good.

### Cleaning recommendations for AISI 439

The cleaning of AISI 439 stainless steel tubes in evaporators was examined in tests with KEBO France. The best solution is to use a caustic solution and to clean by high pressure water or mechanical brushing.

### Tube life

Since 1974, AISI 439 stainless steel tubes have been installed in many cane and beet sugar refineries in Europe, Africa and South East Asia. Their expected service life is about 20 years in evaporators<sup>1</sup> and 30 years in vacuum pans<sup>2</sup>.

### Financial factors

The absence of nickel in AISI 439's chemical composition means that this grade is much less affected by speculation on the global money markets. Consequently, it is possible to:

- Offer a product with qualities identical or superior to AISI 304 or copper, at a lower price (10–15% less expensive than AISI 304, depending on the current nickel price);
- Offer longer price-validity periods, thanks to the relative stability of the price of chromium.

A financial analysis was conducted to compare the different types of tubes. The analysis was conducted over a 20 year operating cycle, corresponding to the expected life of the AISI 439 tubes.

For each material, an operating cost was determined. The operating cost included the purchase price of the tubes, the cost of cleaning (frequency, chemical products used, workforce required), and the lifespan of the tubes.

The results are shown in Figure 4.



Fig. 4—Calculated operating costs for different materials.

The overall cost of the AISI 439 stainless steel is lowest. AISI 304 has a higher purchase price. The cost of carbon steel is lower in terms of purchase price per tonne but the thicker gauge (2.5 mm instead of 1.2 mm, for example) reduces this direct-cost benefit.

<sup>1</sup> AISI 439 tubes used in evaporators in Zambia (Zambia Sugar plc.), Philippines (Central Azucarera San Antonio), Guadeloupe (Gardel), La Réunion (Bois Rouge, )

<sup>2</sup> AISI 439 tubes used in vacuum pans in Mauritius (Savannah, Medine, F.U.E.L, FivesCail continuous vacuum pans), Colombia (Incauca), Philippines (Cotabato), Thailand ( Mitr Phu).

## Conclusions

This study showed that AISI 439 grade stainless steel has advantages in all the following key factors in a 'sugar-processing evaporation' application:

- Thermal conductivity (30% better than an austenitic grade)
- Surface finish
- Mechanical properties
- Corrosion resistance
- The price of the material

## REFERENCES

**ArcelorMittal** (1993). Corrosion resistance of the stainless steel. ArcelorMittal Stainless Europe Research Center, Isbergues (France).

**ArcelorMittal** (2009). Ferritic stainless steel offer K39M Technical Data sheet.

## ACIER INOX FERRITIQUE AISI 439 POUR L'INDUSTRIE SUCRIÈRE

Par

B. MEYER

*ArcelorMittal Stainless Tubes Europe*  
[Bruno.Meyer@ArcelorMittal.com](mailto:Bruno.Meyer@ArcelorMittal.com)

**MOTS-CLEFS: Acier Inoxydable 439, Ferritique,  
Tubes, Échangeur de Chaleur, Économies d'Énergie.**

### Résumé

L'OBJECTIF de ce document technique est d'identifier le meilleur matériau pour tubes d'évaporateurs, de réchauffeurs et de cuites des usines à sucre. On a étudié les conditions de production dans plusieurs usines de canne et de betterave. Les principaux éléments à prendre en compte dans le choix des matériaux pour les tubes étaient; résistance à la corrosion et son effet sur la durabilité du tube; résistance mécanique et son effet sur la structure de l'échangeur de chaleur; conductivité thermique et son effet sur la quantité d'énergie nécessaire; état de la surface et son effet sur l'encrassement et le nettoyage. Plusieurs matériaux ont été testés. L'acier inoxydable ferritique AISI 439 a donné les meilleurs résultats.

**ACERO INOXIDABLE FERRÍTICO AISI 439  
PARA LA INDUSTRIA AZUCARERA**

Por

B. MEYER

*ArcelorMittal Stainless Tubes Europe*  
[Bruno.meyer@arcelormittal.com](mailto: Bruno.meyer@arcelormittal.com)

**PALABRAS CLAVE : Acero Inoxidable 439, Ferrítico,  
Tubos, Intercambiador de Calor, Ahorro Energético.**

**Resumen**

EL OBJETIVO de este artículo técnico es identificar el mejor material para tubos de evaporadores, calentadores y tachos de vacío de los ingenios azucareros. Se estudiaron varias plantas de procesamiento de remolacha y caña para analizar sus condiciones de producción. Las principales consideraciones en la selección de materiales de tubos fueron: resistencia a la corrosión y su efecto en la durabilidad del tubo; resistencia mecánica y su efecto en la estructura del intercambiador de calor; conductividad térmica y su efecto en la cantidad de energía requerida; acabado superficial y su efecto en incrustación y limpieza. Se probaron varios materiales. El acero inoxidable ferrítico AISI 439 dio los mejores resultados.