# SOLAR WATER HEATERS

## THE FERRITIC SOLUTION

ISSF INTERNATIONAL STAINLESS STEEL FORUM

icda

FERRITIC STAINLESS STEEL APPLICATIONS

# Foreword

## WHAT PRICE HOT WATER?

"The new millennium brings with it a new level of concern about the 'cost' of energy. By this I mean not just the ever-rising financial cost to consumers but the cost to the planet of the way we generate our energy, consume non-renewable fuels and pollute our environment in the process.

"For our hot-water needs, solar water heating is a perfect way to harness and exploit natural energy harmlessly, at no cost other than that of a relatively modest initial investment.

"Ferritic stainless steels are particularly advantageous materials for use in all aspects of such installations, from captor panel to hot-water tank. Their low and stable cost and ideal characteristics can make solar water heaters more durable, even less initially expensive and thus accessible to more potential users.

"Given the continued volatility in the price of certain alloying elements, notably nickel, ISSF is encouraging the use of ferritic grades. The ISSF brochure "The Ferritic Solution" and a similarly titled video, provide much-needed general information on these fine steels*. The present booklet is one of several follow-up publications on ferritics in specific applications.

"As with the two initial projects, the International Chromium Development Association (ICDA) has co-funded this booklet. I thank ICDA** for this help, as I do those users of ferritics who have contributed testimonials about the excellence of these grades in solar water heaters."

*Both brochure and video are available free of charge from ISSF and can also be viewed on the ISSF website (www.worldstainless.org) and downloaded.

**ICDA website: www.icdachromium.com

**Jürgen Fechter**
Chairman
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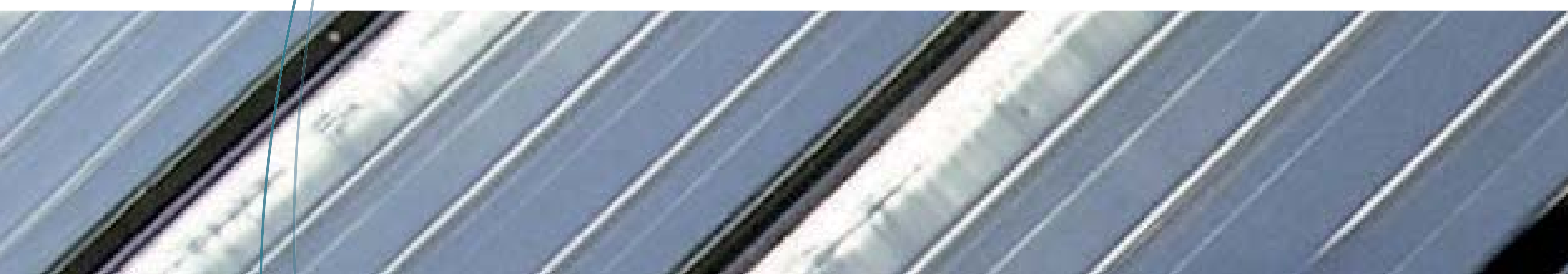


## International Stainless Steel Forum (ISSF)

Founded in 1996, the International Stainless Steel Forum (ISSF) is a non-profit research organisation that serves as the world forum on various aspects of the international stainless steel industry. Whilst having its own Board of Directors, budgets and Secretary General, ISSF is part of the International Iron and Steel Institute (IISI). ISSF now comprises some 73 company and affiliated members in 26 countries. Jointly, they are responsible for around 85 percent of worldwide stainless steel production. A full list of members can be found on the ISSF website: www.worldstainless.org.

# Contents

*"I'd put my money on the sun and solar energy.
What a source of power!
I hope we don't have to wait 'til oil and coal
run out before we tackle that."*

**Thomas Edison**

# FERRITICS: GETTING INTO HOT WATER

Ferritic stainless steels can help us harness the sun's energy in water-heating systems.

Whether we live near the South Pole or in deepest Africa, we all need hot water. Even in the hottest countries, when you're lucky enough to have water at all, it is better for baby's skin to wash it in hot water than in cold. In the developed world, on the other hand, people consider they need hot water all the time – instantly and at the turn of a tap. Life without it is unimaginable.

There's no denying that a having hot water is important. A hot shower, for example, is good for the health and good for the skin. Hot water kills bacteria. It reduces the need for detergents or washing-up liquid, which in turn reduces the need for used-water treatment. And nobody ever made a decent cup of coffee without it. The list of advantages is endless.

## ENERGY GAP

Heating water requires energy – and therein lies a problem. Our evolving life style seems to need more and more of it and energy is getting increasingly expensive. Not only that, our ways of creating it or our sources of energy are either damaging the planet or simply drying up.

In consequence, we're more than ever aware that we must all save energy, both to stave off planetary disaster and simply save money.

## FREE HOT WATER FROM THE SUN

Solar water heating has been around for some years as a way of harmlessly harnessing the massive energy in sunlight and making free hot water. As a solution it is looking more and more interesting, as time passes, for both the developed world and poorer regions.

In countries where energy-production is weak or there is low investment in power, tapping solar energy is an obvious answer. In countries where there is great poverty, too, free solar power can obviously also help. An advantage is that a basic solar water heating system works on very simple principles, can cost little to install and usually requires minimal maintenance.

***"...a basic solar water heating system works on very simple principles..."***

In developed societies, consumption peaks put a huge strain on power stations twice a day. Solar water heating can alleviate this phenomenon. And, of course, it's free! Estimates vary as to the amount of domestic water heating consumption per household it is likely to satisfy.

It is reckoned that in certain very hot climates, solar water heating can provide up to 85% of a household's hot water! The solution does not just apply to sunny countries, however. Often a lack of sun can be offset by incorporating an electrical heating element or connection to a gas or fuel-oil heating system, thus creating a combined system.

And of course, its uses are by no means confined to domestic situations. Solar energy can be used to heat water in home, business and industrial contexts. Heated swimming pools and underfloor heating are interesting examples.

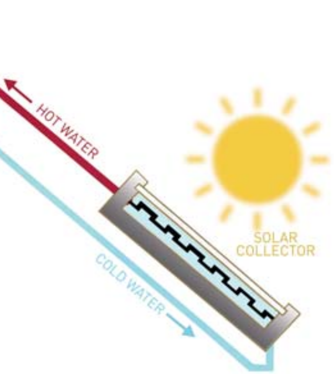
Following the Kyoto Protocol, governments are actively encouraging and subsidising the use of solar water heaters, in their own countries and elsewhere. In the present "climate" the market for solar water heater installations is growing and is set to boom in the years to come.

China is now the leading country in solar energy production and is by far the largest producer of solar water heater systems. Recently, in Spain, over 50 towns have made the installation of solar panels for domestic water heating obligatory in all new-build or renovated homes.

## FERRITICS: PART OF THE SOLUTION

A solar water heating system consists essentially of a collector system (flat plate or evacuated tubes) and a water storage tank. Various metals are currently used in the construction of these two elements.

Ferritic stainless steels are a highly suitable material for use throughout such systems. From a technical point of view, they have various advantages, not least of which is their resistance to corrosion. They are also relatively low in initial cost and, being highly durable and trouble-free, offer significant Life Cycle Cost advantages. Stainless steels are also 100% recyclable.



THE THERMOSYPHON PRINCIPLE

***"Ferritic stainless steels are highly suitable for use throughout such systems."***

At the time of writing, numerous manufacturers already use stainless steel. Some use ferritic grades, having understood their significant economic advantages.

## THE MAGIC OF STAINLESS STEEL

This amazing material is renowned above all for its resistance to corrosion and its attractive appearance. Both are due to the presence of chromium as an alloying element. Steel has to contain at least 10.5% of it to become "stainless" (i.e. highly corrosion-resistant).

Stainless steel also boasts physical and mechanical properties that make it an exceptionally useful and desirable material for the widest variety of applications.

On the production and assembly front, it offers ease of manufacture and excellent workability and weldability. For the end user, it guarantees long service life. It usually needs no surface treatment (such as painting) and is easy to keep clean and maintain.

Until recently, the use of stainless steel in solar water heating systems has tended to favour austenitic (300 series) grades. Intrinsically expensive because of their nickel content, austenitic grades are at the mercy, in terms of their initial cost, of the soaring and volatile nickel price.

## FIVE FERRITIC FAMILIES

ISSF classifies ferritic grades in five groups – three families of "standard" grades and two of "special grades".

As well as chromium, the higher-alloyed grades contain small quantities of additional elements such as molybdenum, titanium and niobium, to enhance specific properties.

THE 5 GROUPS OF FERRITIC GRADES

| Group 1 | Group 2 | Group 3 | Group 4 | Group 5 |
|---|---|---|---|---|
| 10%-14% | 14%-18% | 14%-18% stabilised | Added Mo | Others |
| Types 409 and 410 Cr content: 10%-14% | Type 430 Cr content: 14%-18% | Types 430Ti, 439, 441, etc. Cr content: 14%-18%. Include stabilising elements such as Ti, Nb, etc. | Types 434, 436, 444, etc. Mo content above 0.5% | Cr content of 18%-30% or not belonging to the other groups |

**Group 1** grades can be perfectly adequate for applications in non-corrosive or lightly-corrosive environments. Type 430 (**Group 2**) is the most widely used ferritic grade, with better corrosion resistance. It can often replace austenitic Type 304. **Group 3** grades, offering enhanced formability and weldability, are also often used to replace Type 304. **Group 4** grades have added molybdenum, giving extra corrosion resistance – equivalent to that of Type 316. **Group 5** grades are superior to Type 316 in corrosion resistance.

## THE FERRITIC FUTURE

There is a widely-held false belief that only austenitic stainless steel grades really resist corrosion. This idea, which has lingered in user's minds, causing them to sniff at grades that contain no nickel, is totally false! Nickel is not the basic corrosion-resistance ingredient of stainless steel – chromium is.

Stainless steel grades not containing nickel are known as "ferritic" (400-series) grades. Ferritics are highly resistant to corrosion – and especially to what is known as localised or "pitting" corrosion. In many applications, a ferritic grade can be found that can do the job just as well as an austenitic and in certain cases better.

The individual level of corrosion resistance of ferritic grades is mainly determined by the amount of chromium they contain. Chromium is historically stable in price, and this stability is reflected in the price of these intrinsically very affordable grades.

***"The individual level of corrosion resistance of ferritic grades is mainly determined by the amount of chromium they contain. "***

Inner tank, Type 441

Envelope, Type 430

Finished tank

## Viewpoint

**CHARLES PEPIN**
FACTORY MANAGER
SUNTANK
SOUTH AFRICA

*"Suntank has always used ferritic grades of stainless steels since the company was established some 12 years ago. Stainless steel has important corrosion-resistant properties in an application that deals with water.*

*"More specifically, we use Type 441 for the tank interior, since it has the rare quality of being able to tolerate both heat and pressure at the same time. This advantage obviously affects the product right from design stage. For the heat-exchanger envelopes, on the other hand, we prefer to use ferritic Type 430, for cost reasons.*

*"From a manufacturing point of view, these ferritic grades have never given us any problems and behave well in terms of forming and welding. Neither have there ever been any problems with them reported during the service life of the systems. We're happy with ferritics. They are both economical and good quality and serve our purposes ideally."*

# THE FERRITIC ADVANTAGE

Reasonable cost and superior technical qualities make ferritics the perfect choice.

A blend of practical experience and development research makes it plain that ferritic stainless steels can profitably be used throughout an entire solar water heating system. These steels are ideally suited to not only the hot water tank but also the collector panel and the collector-panel frame and the heat exchanger.

## CORROSION-RESISTANT OUTER TANKS

The hot water tank in solar water heating is a critical part of the system and must be made of the most suitable material. Generally, it consists of an inner and an outer tank. The inner tank contains the heated water and is usually insulated, to keep the water hot for longer. The outer envelope protects the insulator and keeps it in place.

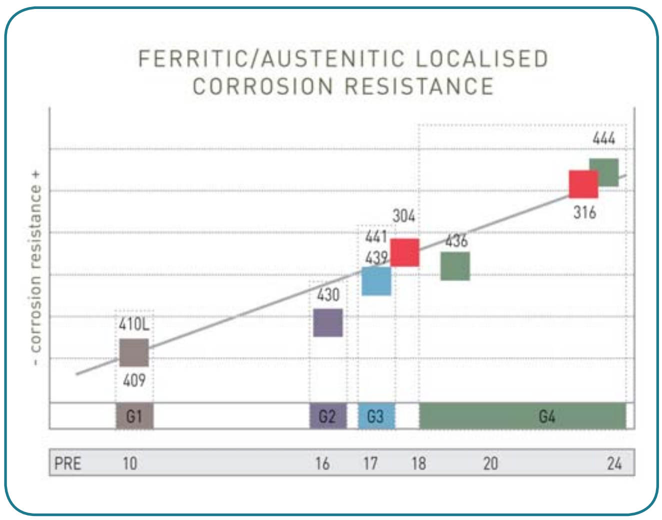
## Localised corrosion resistance

Several years ago, in Europe, Japan, Australia and elsewhere, producers of electric hot water tanks started replacing the traditional enamelled-steel solution with stainless steel. The corrosion-resistance of stainless steel meant they could offer a much longer-lasting product. At first they preferred Type 316 – a nickel-containing austenitic grade (with molybdenum).

Later, to help manufacturers make savings, stainless steel producers proposed ferritic grade Type 444 (group 4). Containing 18% chrome and 2% molybdenum, this grade delivers a resistance to localised (pitting) corrosion at least as good as that of Type 316, if not better.

Type 444 costs less than Type 316 (and its price is more stable) but is every bit as good in the application.

Austenitic and ferritic grades can be seen as two interchangeable stainless steel families, in terms of their resistance to localised corrosion.



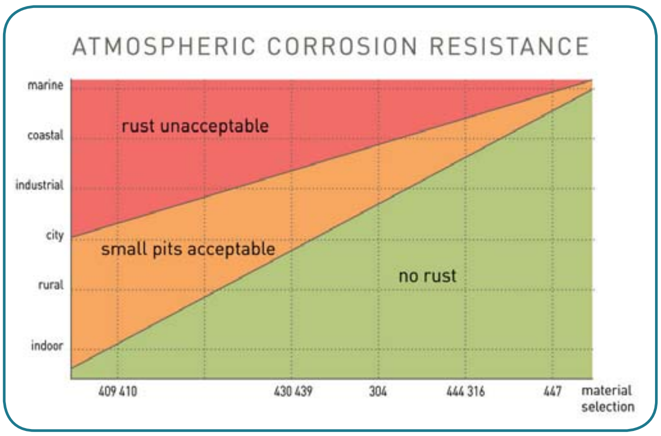

The PREN (Pitting Resistance Equivalent Number) – %Cr +3.3 %Mo+ 0.16%N – is a measure of the pitting-corrosion resistance of a stainless steel grade in a chloride-containing environment. The higher the PREN the greater the corrosion resistance.

A comparison of the corrosion resistance of the five ferritic "groups" with that of austenitic Type 304 highlights the key role of chrome and molybdenum. It shows that the corrosion resistance of most ferritics matches that of nickel-containing grades.

***"...the corrosion resistance of most ferritics matches that of nickel-containing grades."***

## Atmospheric corrosion resistance

The main requirement of the steel used for the envelope is that it should resist atmospheric corrosion – mostly for reasons of appearance. Depending on the atmospheric conditions, ferritic grades ranging from Type 430 up to Type 444 are all suitable for this application.




The surface roughness of the envelope will have an important effect, of course. Bright Annealed (BA) or mirror finishes are best, since they do not trap dirt and deposits that might encourage corrosion. The smoother the better.*

## Easy fabrication

The replacing of enamelled steel or Type 316 with Type 444 was accompanied by technical assistance from the steel producers, notably involving optimising Type 444's welding parameters. The steel producers also helped by working with tank fabricators on optimal manufacturing methods – looking at cold-working behaviour, design optimisation, and finishing, for example.

As a result, today, many manufacturers use Type 444 instead of enamelled steel and Type 316. In so doing they get a better product and (with regard to Type 316) a less expensive one.

Welding a Type 430 heat exchanger onto a Type 441 inner tank

## Viewpoint

**RAIMO AALTONEN**
INDUSTRIAL DIRECTOR
KAUKORA OY
FINLAND

*"We've been manufacturing water heaters for a long time.*

*"Tanks in the water-heater market in Finland used to be dominated by copper-coated enamelled steel hot water tanks. At one point, Kaukora made the courageous decision to start making tanks in ferritic stainless steel. Finding the right ferritic grade wasn't easy. It took numerous tests and studies before we found the grade for us, which turned out to be stabilised grade 1.4521, otherwise known as Type 444.*

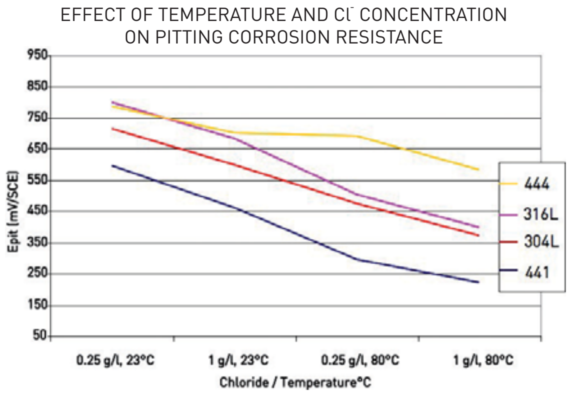
*"In the seven years since we started using this grade, we haven't had a single complaint. This speaks clearly for the technical superiority of this stainless steel in solar water heaters."*

*The ISSF brochure The Ferritic Solution, mentions experience with truck trailer envelopes, sometimes made in Type 430 with a BA finish.

# TOUGH INNER TANKS

The inner tank has to deal with the hot water itself. Here, the effect of high temperatures on the various stainless steel grades is especially interesting. At elevated temperatures, ferritic Type 444 performs much better than austenitic Type 316 in terms of localised-corrosion resistance.

Clearly, Type 444 is the optimal solution here, in terms of both properties and cost.




## Good welding practice

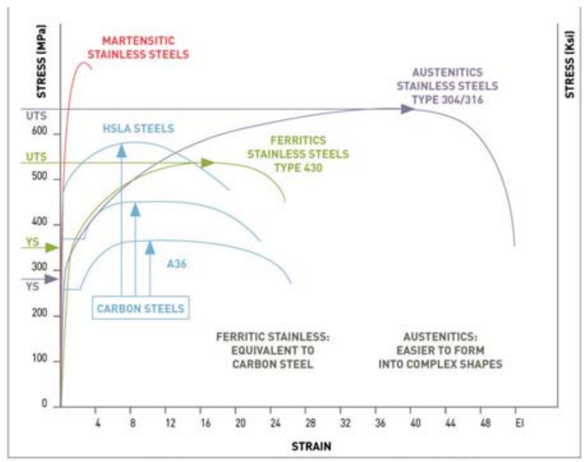
Particular attention should be paid to correct welding, since if it is not performed correctly, intergranular corrosion in the heat affected zone (HAZ) can diminish the steel's performance. With correct welding procedures, however, this grade's superb corrosion-resistance is not lost.

Inner tank, Type 444

## Higher yield strength

A hot water tank is generally considered a "pressure apparatus". The dimensions of these hot water tanks correspond to the specifications in various norms*.

These codes determine, amongst other things, the minimum thickness of the metal to ensure resistance to explosion. The allowable resistance is generally the yield strength at maximum operating temperature.




UTS is measured in Mpa (1Mpa = 1N/mm² = 145PSI = 0.1kg/mm²) and represents maximum resistance at failure. YS refers to the beginning of the "plastic" phase, where elongation no longer disappears when the stress is removed.

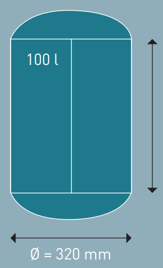
Ferritics have higher yield strength than austenitics. A glimpse at the graph shows that at 100°C (above that required for a hot water tank) the yield strength of ferritics decreases less than that of austenitics at high temperature. Its behaviour is actually better than that required in the Euro EN norms.

| | YS 0.2% at 20°C | YS 0.2% at 100°C |
|---|---|---|
| 1.4509/Type 441 | 300 | 230 |
| 1.4521/Type 444 | 360 | 300 |
| 1.4301/Type 304L | 320 | 260 |
| 1.4401/Type 316L | 320 | 170 |

*EN 13445 unfired pressure vessel, CODAP 2005 French code for construction of pressure vessel, ASME boiler and pressure vessel code.

## WEIGHT SAVING WITH FERRITIC

**316 design**
Th. = 2.0 mm
W = ± 24 kg




**Ferritic design**
Th. = 1.35 mm
W = ± 16 kg

Δ = - 8 kg

This important factor, plus the fact that ferritics are not at all prone to stress corrosion cracking, means it is possible to reduce the thickness of the steel used to make a tank.

## Viewpoint

**KARL MORRISON**
GENERAL MANAGER
ENDLESS SOLAR
AUSTRALIA

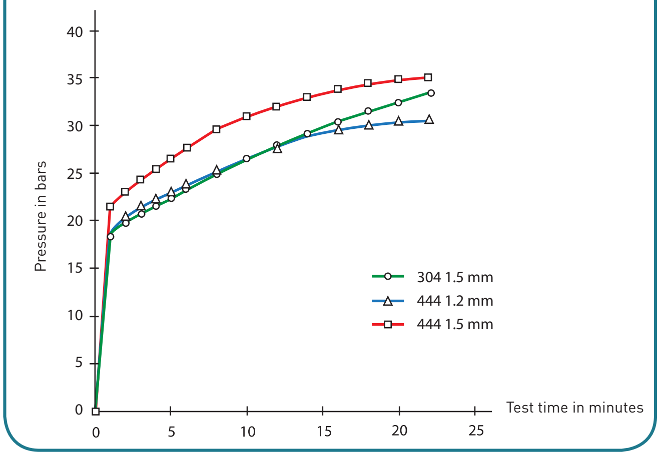
*"We've used Type 444 'marine' grade for the inner cylinders of our tanks from day one. In Australia, manufacturers are used to producing vitreous-enamel 'glass-lined' tanks. In solar applications, water temperatures are higher than with standard water heating, rising to 100°C, so with expansion and contraction the glass cracks. Glass cylinders last from 7 to 14 years. Our ferritic tanks, which we guarantee for 10 years, should last over twice as long.*

*"Then there's stainless steel's corrosion resistance, which means there's no need for a sacrificial anode and no need for maintenance. Our tanks are durable and solid. In fact, they're considered the best of their kind on the market. Their toughness also makes them easy to transport.*

*"Regarding fabrication, making a tank is straightforward. The design must place the welds correctly, but there's nothing to cause production difficulties.*

*"In Australia, there are great government incentives for 'going solar' now. Although stainless steel is considered a premium storage solution, the LCC gains are clear."*

This is confirmed by explosion testing on 150-litre tanks, where it can be seen that a tank in Type 444, 1.2 mm thick is as safe as one in Type 304 at 1.5 mm.




## THE SOLAR COLLECTOR

The role of the collector is to absorb solar radiation. There are two basic types.

The simple flat type consists of a thin absorber sheet (to which a black or selective coating is applied), backed by a grid or coil of fluid tubing and placed in an insulated casing with a glass cover. Fluid is circulated through the tubing to remove the heat from the absorber and transport it to the tank, to a heat exchanger or some other device.

The vacuum-tube collector (or "evacuated tube") type consists of parallel rows of glass tubes, each tube consisting of a glass outer tube containing a small-diameter inner absorber tube (traditionally in copper) attached to a fin. The tubes are covered with a special light-modulating coating.

Ferritic stainless steel welded tubes could, in fact, be an excellent solution for vacuum-tube systems. The thermal expansion coefficient of ferritics is very close to that of glass and much lower than that of austenitic grades. Also, due to the density of ferritic stainless steel (7.7 Kg/dm$^3$), tubes made in this material are considerably lighter in weight than copper tubes (8.9 Kg/dm$^3$).

## FERRITIC v GLASS & COPPER

| | Ferritic | Glass | Copper |
|---|---|---|---|
| α (10$^{-6}$/°K) | 10.5 | 9 | 16.5 |

## Ferritic flat-panel solution

It is also possible today to produce an optimised flat collector from relatively thin, stamped and spot-welded ferritic stainless steel sheet. Manufacturing this type of collector is a very accessible prospect for any manufacturer.

A major advantage of this type of panel over the traditional flat panel of black-painted copper tubes, is the greater heat-exchange surface – 98% as opposed to 30%.

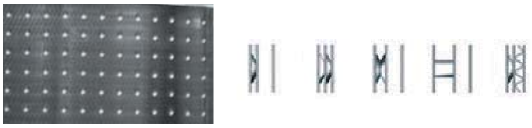
Such flat panels consist simply of a dark, cushion-type, absorber panel. Various techniques can be used to provide the finish – which always involves a black surface, for maximum absorption of solar radiation. These range from sophisticated electro-chemical treatments to simple black painting. The latter may not be quite so efficient, but in some parts of the world an economical solution of this kind would be more than adequate.

### 100% FERRITIC STAINLESS STEEL SOLAR PANELS

**A traditional solar panel typically consists of a wide frame in anodised extruded aluminium, with a tempered solar glass cover. Inside is a solar-reflective copper fin, black chromed over a special nickel substrate and welded to copper tubes by ultrasonic technology. Underneath there is thick insulation.**

**A ferritic stainless steel panel might have a frame of Type 441, for example, and a stand in Type 410. The collection of solar radiation would be by stamped and spot welded "cushion panel", in ferritic Type 444. Various possible profiles for such panels are illustrated below. In certain countries, the use of this type of absorber may even make it possible to dispense entirely with the panel's glass covering.**

**A heat exchanger in black ferritic Type 431 would replace the copper tubes. Finally, the backing insulation would not have to be as thick as is the case with a traditional design.**



No fins or tubes are required – just a black ferritic heat exchanger. With ferritics, this type of panel can be used with or without glass covering. Indeed, this technology makes it possible to replace ordinary roofing sheet with uncovered ferritic panelling, so that the solar-energy solution is an integral part of the building envelope.

Ferritic stainless steels also have excellent resistance to corrosion – notably from fluids including antifreeze (such as glycol) that may be used in solar water heater systems in regions subject to frost.

## CORROSION-RESISTANT FRAMES

Collectors must be surrounded by a frame. Today, this frame can be fabricated in ferritic stainless steel. The wide range of available ferritic grades means there will always be an ideal grade for any given atmospheric environment. Thanks to their high mechanical properties, ferritic frames can be much thinner than is possible with other materials. This means that they can be of similar weight to a frame made in a so-called "light metal" (which will not have stainless steel's corrosion resistance).

***"...ferritic frames can be much thinner than is possible with other materials."***

## STRONG STANDS

The stand of a solar water heater panel must also be light, but strong enough to support the weight of the unit. It should also be corrosion resistant and require no maintenance.

The excellent mechanical properties of ferritic stainless steel Type 430 – or even 1.4003 (Type 410), which is an even lower-cost option – are very useful here. Cost is obviously important for this part of the installation, which is why standard ferritic grades are the best solution.

In a more aggressive environment, 1.4003 (Type 410) could be painted, to assist its resistance to corrosion.

Ferritics have a higher Young's modulus than competing materials, of 210 $KN/mm^2$. That of copper is 132 $KN/mm^2$ and that of aluminium 65 $KN/mm^2$. This and their high yield strength give ferritic structural members (profiles and/or tubes) of the stand of a solar water heater system high torsional strength, particularly at high temperatures.

## RECOMMENDED FERRITIC GRADES

- **Inner tank: 444, 441 (depending on water quality)**
- **Outer tank: 430, painted 409, 439, 441, 444 (for seaside environment)**
- **Collector (incl. frame and tubes and plate): 441, 444**
- **Stand: 430 or painted 409/410**
- **Tubes for joining system: 444**

| | Type | Element | |
|---|---|---|---|
| | | Cr | Mo |
| 10%-14% Cr Group 1 | 410 | 10.5-12.5 | |
| 14%-18% Cr Group 2 | 430 | 16.0-18.0 | |
| 14%-18% Cr stabilised Group 3 | 430J1L | 16.0-20.0 | |
| | 439 | 16.0-19.0 | |
| | 441 | 17.5-18.5 | |
| Added Mo Group 4 | 444 | 17.0-20.0 | 1.75-2.5 |
| Others (>19% Cr) Group 5 | 445 | 19.0-21.0 | |

Non-exhaustive list. See ISFF brochure "The Ferritic Solution" pp. 60-61 for full details.

## FERRITIC PROPERTIES AND ADVANTAGES

**Compared to carbon steel:**

- **Better resistance to atmospheric corrosion without additional coatings**
- **Longer life and lower life cycle costs (LCC)**
- **Ferritic is suitable for both coil and hot water tank**
- **Easy to recycle**

**Compared to austenitic stainless steel:**

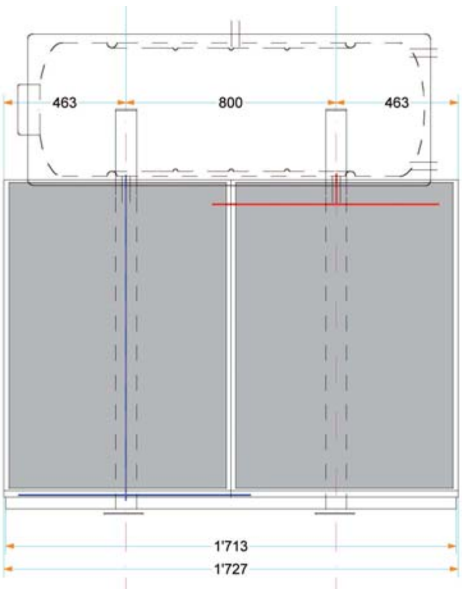
- **Lower and more stable price**
- **Lower thermal expansion coefficient**
- **Better oxidation resistance**
- **Higher thermal conductivity**
- **Higher yield strength**
- **Not prone to stress corrosion cracking**
- **Possibility to decrease thickness**

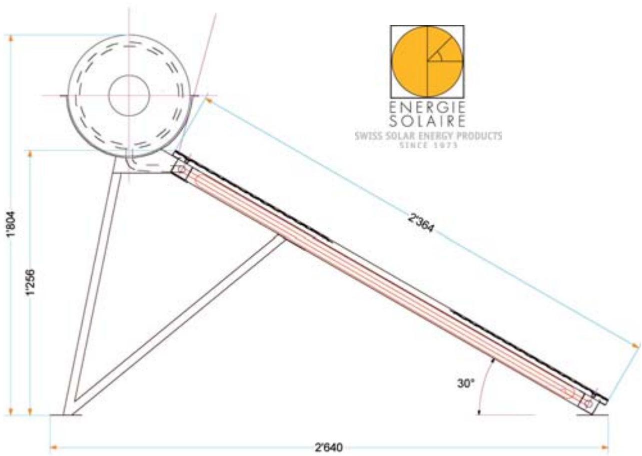
## DEMO PROJECT

Convinced of the importance of promoting the use of ferritic stainless steels in solar water heater systems, ISSF has sponsored a demonstration project, in collaboration with two European manufacturers.

The aim of the project is to demonstrate that ferritic stainless steel is a suitable material with which to manufacture a complete thermosyphon system. The thermosyphon method was chosen in order to illustrate a simple and durable system suitable for hot-water production in hot countries.

The Swiss company, Energie Solaire SA, produced the design for the absorber panel and its stand. The 4 $m^2$ absorber panel consists of two spot-welded Type 444 ferritic sheets, 0.6 mm thick. It is used without any glass covering. Taking into account the specific properties of ferritic grades, the design aims to obtain the most efficient system possible.

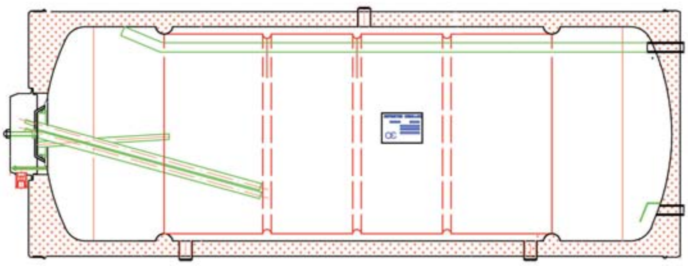



ENERGIE SOLAIRE
SWISS SOLAR ENERGY PRODUCTS
SINCE 1973

The 270 l capacity tank, designed and manufactured by the Spanish company Depositos Coballes S.L., uses Type 444, 1.5 mm and 2.0 mm thick.

Performance-measurement of this 100% ferritic system is proving that the system is highly competitive in terms of production of solar water heating.



Depósitos Coballes, S. L.

## CONVERTING TO FERRITICS

To sum up, ferritic stainless steels are nickel free, hence their price is far stable than that of austenitics. This makes it much easier for a manufacturer to manage costing, purchasing and selling. Inventory cost is also low.

Ferritic stainless steels have excellent formability and are suitable for bending, cutting and drilling. Since there are many grades, correct grade selection will always give you good corrosion resistance, good strength and lower price, while meeting the customer's requirements. And compared with carbon steel, ferritic stainless steels offer significant weight reduction.

"Ferritic grades have already proved their worth in hot-water tanks and are a well-accepted solution. Certain ferritic grades offer properties of resistance to atmospheric corrosion that makes them more or less ideal for the frame and stand of the solar collector panel.

"Finally, a simple technology of assembling two ferritic stainless steel sheets together to make a super-effective absorber panel is gaining widespread acceptance. This may well be the solution of the future.

"The solar water heater market is a very obvious market in which ferritic stainless steels can play a dominant role. The technological and economic merits of these (100% recyclable) steels in this sector are clear. We at ISSF sincerely hope that its use will further the cause of environmentally friendly approaches to "energy" around the world.


## ACKNOWLEDGEMENTS

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