

Marine Scrubbers

Exhaust Gas Cleaning



Tough demands are our business

Founded in 1930, VDM Metals developed into a world market leader for high-performing metallic materials. The quality of our products and services is the result of long-term experience, our integrated production chain and a sales network that spans the globe. VDM serves the most demanding industries and is backed by a strong R&D and Application Engineering force.

VDM Metals produces high-performance nickel, cobalt and zirconium alloys as well as special stainless steels for the use in extreme conditions. Our materials are made to last, resisting heavy mechanical and thermal stresses as well as extremely corrosive environments – sometimes all three simultaneously. In many key technologies high-performance alloys from VDM Metals are indispensable for the industrial-scale implementation and safe control of essential processes in hot or corrosive environments.

Materials are delivered as plate and sheet, strip, wire, rod and bar, or welding consumables. Our processing plants and machinery are tailored to specific production requirements and local conditions and equipped with state-of-the-art process data acquisition systems, ensuring high productivity and production reliability. Our integrated manufacturing chain means that all major production steps are in our own hands – a vital prerequisite for a robust and stable manufacturing process. The result of our efforts: maximum purity, homogeneity, reproducibility and optimal processing characteristics of our products. Thus, we offer nothing less than premium materials in any form needed as well as first class service, available anywhere in the world.

Material concept for reliable operation

Flue gas desulfurization (FGD) is a very familiar application for VDM Metals. Since the 1970s, FGD is a standard principle for stationary coal-fired power plants for the reduction of pollutant in the environment. Meanwhile the concept of flue gas cleaning has been adapted to marine engineering. In both industries VDM gathered extensive experiences. We believe that the right material choice is key. VDM Metals develops individual material concepts that are adapted precisely to the different conditions within the exhaust gas cleaning system. The flow of the cleaning process and its different corrosive and temperature conditions need to be considered to prevent expensive damages or a complete failure of the system.

Together with our customers, VDM develops material concepts that take cost effectiveness and the longevity factor of these systems as well as legislative compliance into account. Even more, VDM Metals has developed several alloys that withstand the highly demanding conditions in specific parts of the FGD plants regarding corrosive media and temperature, such as VDM® Alloy 31, Alloy 31 Plus, Alloy 59 and Alloy 2120 MoN. The longevity of the materials is obvious and proven by long-term usage.

Safety, reliability and longevity are the cornerstones of all plant construction and environmental protection projects. It does not matter whether you are working in the area of FGD engineering for diesel engines or in power plants: VDM Metals is your ideal partner for demanding material requisition and offers a professional support for the implementation of critical applications.

Service and support

Our solutions for logistics are adapted to the special needs of the marine engineering industry. We are able to offer custom-made cut-offs for scrubbers in newly designed vessels or retrofit of scrubbers.

When special support is needed on material selection during design and planning, our application engineers are at your disposal. They support your project with longtime experience regarding demanding environments of applications in highly corrosive media. Our Welding Technology Center of Excellence will gladly support you with any welding questions regarding construction with the special requirements of nickel alloys.

We perform extensive tests according to the respective customer specifications which demand for mechanical properties, corrosion and high temperature characteristics as well as soundness and longevity of each single product. Thus, we are contributing to planning, construction and realization of complex projects like flue gas desulfurization plants.

Corrosion in exhaust gas cleaning systems

The life span of flue gas desulfurization systems depends significantly on the chosen material and its corrosion resistance. When using inappropriate stainless steels or alloys, the composition of the exhaust gases may cause corrosion that leads to damages of the scrubber in a short period or to a complete failure of the system.

Nickel and nickel alloys have proven resistance to a wide variety of aqueous corrosive environments typically encountered in flue gas cleaning technology. Nickel by itself is a versatile corrosion resistant metal. More importantly, its metallurgical compatibility over a considerable composition range with a number of other metals as alloying elements has become the basis for many binary, ternary, and other complex nickel alloy systems. The result of this is a very unique and specific corrosion resistance, which can be used to handle the different levels of corrosive impact in flue gas cleaning equipment.

The incineration of sulfuric heavy fuel form sulfuric oxides, sooty particles and nitrogen oxides in the exhaust gas scrubbers.

The alloys used in these scrubbers are exposed to sulfur and chlorides from the exhaust gases, and the seawater causes a high wet corrosion load. Coaction of these different parameters may cause different types of corrosion. In general, the following types of corrosion can be distinguished in scrubbers for gas cleaning:

- General corrosion
- Intergranular corrosion
- Pitting corrosion
- Crevice corrosion

General corrosion

The simplest form of corrosion is uniform or general corrosion. This type of corrosion is almost uniform across the entire surface and can be easily countered by an appropriate increase of sheet and plate thickness.

Intergranular corrosion

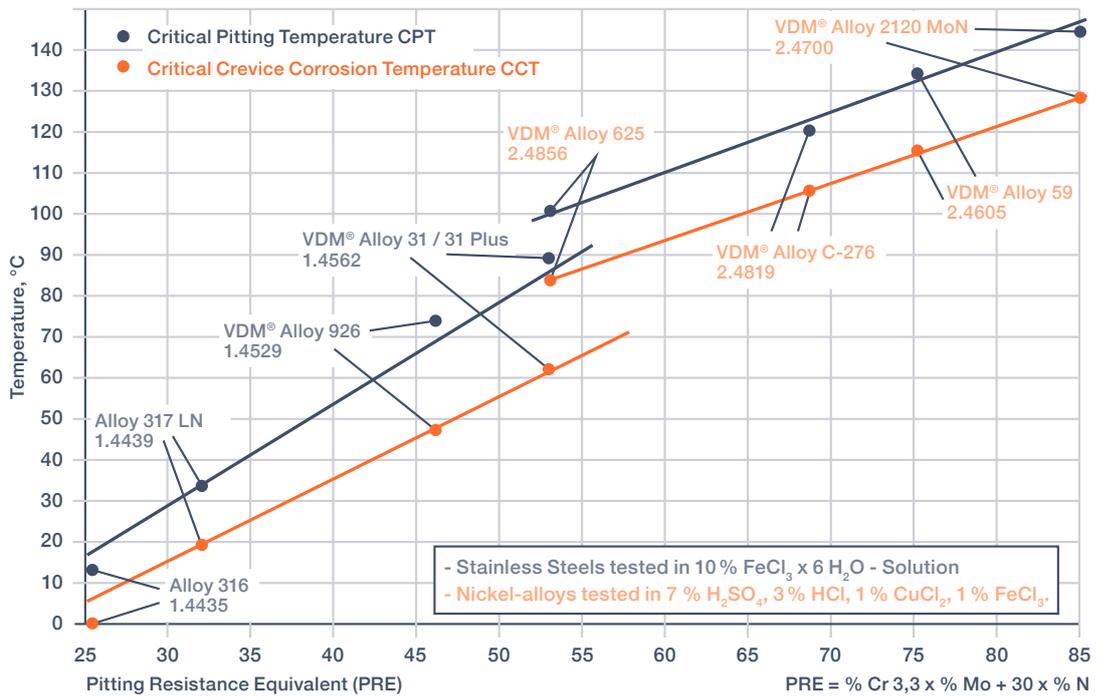
Intergranular corrosion or attack is a form of corrosion which occurs in or adjacent to the grain boundaries of a metal. Some Nickel alloys and stainless steels may become susceptible to intergranular corrosion as a consequence of their carbon and tungsten content after heat treatment. VDM® Alloy 31, Alloy 31 Plus, Alloy 59 and Alloy 2120 are much more resistant to intergranular corrosion than other comparable alloys.

Pitting and crevice corrosion

In any chloride-containing medium like flue gas desulfurization plants and scrubbers for diesel engines, pitting and crevice corrosion are always the most critical forms of corrosion. Both types of corrosion are based on similar electrochemical effects and become more critical with rising chloride concentration, increasing temperature and decreasing pH.

The corrosion resistance of stainless steels and nickel alloys is due to the spontaneous formation of a thin but very dense layer mainly consisting of chromium oxides. A local breakdown of this so-called passive layer and the presence of chlorides result in the typical pitting or pinhole corrosion. Crevice corrosion also refers to a breakdown of the passive layer in crevices due to lack of oxygen and the concentration of chlorides. This is followed by an enhanced corrosion in this area. Such crevices can be formed by construction, e.g. under flanges, nuts and bolts or under deposits.

Because of the high corrosion resistance of the special stainless steels and the nickel-based alloys used in scrubbers, several highly aggressive tests have been established to compare and rank these materials.



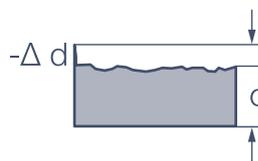
The higher the PRE number of an alloy the higher are the Critical Crevice Corrosion Temperature (CCT) and the Critical Pitting Temperature (CPT)

One of these tests is the determination of the so-called Critical Pitting Temperature (CPT) or Critical Crevice Temperature (CCT) as a function of the Pitting Resistance Equivalent Number (PREN) which is determined from the alloy composition. The main alloying element for the majority of nickel alloys is chromium, which is necessary for a stable passive surface layer, upon which the corrosion resistance depends. Besides chromium, molybdenum is another important alloying element that increases the resistance to pitting and crevice corrosion. The combination of nickel, chromium, molybdenum and nitrogen is decisive for the resistance of the alloy against localized corrosion.

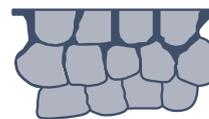
Of course, one should always bear in mind that these tests only reflect laboratory results and no gas cleaning system is operated with these kinds of chemical solutions. Therefore, values like CPT, CCT or PREN can only be used to rank the materials, but they do not replace actual field tests or experience with existing systems.

Alloys from VDM Metals have shown their outstanding performance in scrubbers for sulfur removal for more than two decades.

Main types of corrosion



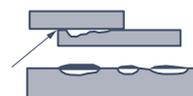
General Corrosion
 Avaluable corrosion rate
 $g/m^2 \cdot d$ (mm/a)
 f (medium, conc., T)



Intergranular Corrosion
 Preferential attack of precipitations containing grain boundaries, e.g. stainless steels (too high C, not stabilized)
 f (medium, annealing, welding, T)



Pitting Corrosion
 Local corrosion at passivable alloys preferentially by chlorides (Br^- , J^-) also at inclusions as MnS
 f (Cl^- , v, T, pH)



Crevice Corrosion
 Local corrosion in narrow crevices, under deposits, in sealings at passivable alloys in chloride media
 f (Cl^- , T, v, O_2 , pH)

See: Nickel alloys and high-alloyed special stainless steels
 Dr. U. Heubner, Dr. J. Klöwer, Dr. H. Alves, Dr. R. Behrens, V. Wahl, Dr. M. Wolf
 Pages: 41-43; Expert Verlag, 2012

Strong materials for demanding applications

Exhaust gas cleaning for marine applications

The principles of the scrubber technologies have already been proven in stationary power plants. Over the last decades, when air pollution and acid precipitation became an issue, strict regulations for air purification were put into place. VDM Metals decided early-on to do its part to overcome these challenges with the development of new alloys and helped its customers comply to the new regulations with meaningful systems. VDM Metals applies its extensive knowledge and long-term experience in the production of corrosion resistant materials for application in flue gas desulfurization facilities.

In order to comply with the relevant oceanic and environmental legislations of the International Maritime Organization (IMO) concerning the limitation of pollution emission – especially regarding SO_x and Particulate Matter (PM) – cleaner exhaust gas has become indispensable. Marine scrubbers are an economical and environmentally friendly solution. They are designed to remove sulfur oxides from the exhaust gases of the engines. The performance of the alloys has been proven over many years of operation in coal-fired power plants or waste incinerators.

For marine applications, three different types of scrubber systems are in place:

A closed loop, an open loop and a hybrid solution. The principle of all three systems is a purification procedure of the exhaust gas to bind sulfur oxides and other particles. Regardless of which technique is used, the construction material has to be corrosion resistant as flue gas and seawater contain sulfur and chlorine and form a highly corrosive environment for the asset. Both chemicals cause different types of corrosion and choosing the wrong material can cause severe damage or even failure of the entire system.

1

Working principle of an open loop system

The open loop scrubber system uses seawater and its natural alkalinity for cleaning the exhaust. The exhaust gas enters the scrubber and is sprayed with seawater. The sulfur oxide of the exhaust gas reacts with the water and forms sulfuric acid. The system does not need any caustic soda. Afterwards the water is led through a filter system, where it is diluted to raise the pH to the natural pH of the surrounding seawater before discharging. The amount of dilution water depends on the area where the vessel is operating. The residue of the filtration process is collected in sludge tanks and can be disposed at harbors providing waste management devices. This scrubber system can be used in most parts of the oceans where alkalinity levels are sufficient.

the scrubber and is sprayed with wash water that has been saturated with an alkali, for example caustic soda (NaOH) or magnesium oxide (MgO). The sulfur oxide of the exhaust gas reacts with this solution and binds as a salt; the sulfur oxide is neutralized. The cleaned exhaust gas exits the scrubber through a demister. The dirty water is filtered and sludges are collected in a tank. The water is inspected and can be discharged without harm to the environment or can be stored in a separate tank when the vessel is in a zero-discharge area. The alkalinity levels of the sea water do not have to be considered as water is mixed with an alkali to increase the alkalinity for the chemical reaction with the sulfur emission. This system is used in harbors and in water with low alkalinity levels like the Greater Sea areas. The tanks with the sludge and collected water can be discharged at harbors offering waste management systems.

2

Working principle of a closed loop system

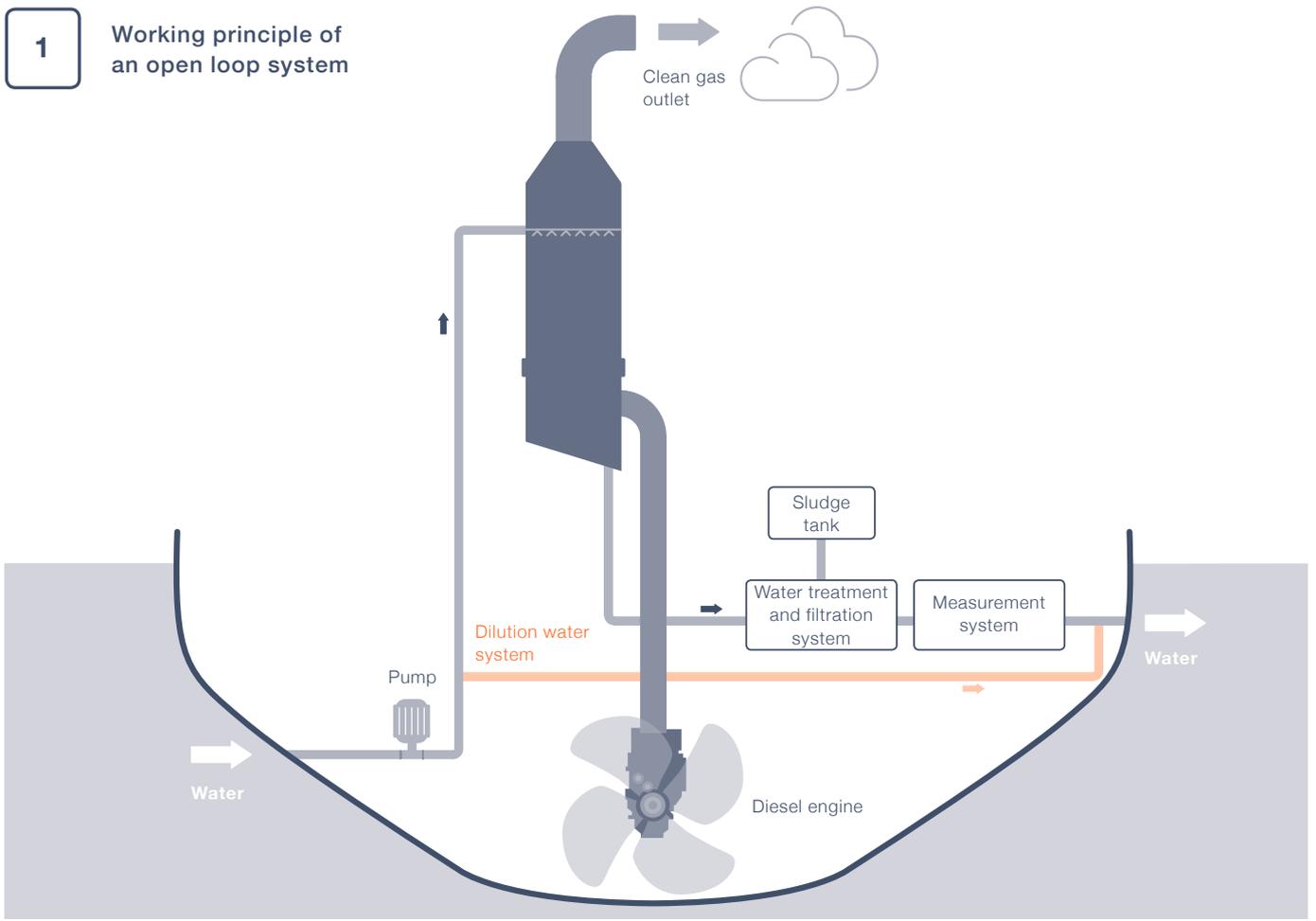
The closed loop scrubber system works continuously in a closed loop, circulating the wash water within the scrubber. The exhaust gas of the diesel engine enters

Hybrid system

An alternative scrubber system is a hybrid solution. This system can operate in both, a closed and an open loop, which provides complete operational flexibility. It can be used in low alkaline waters like the Greater Sea areas and as an open loop system in the oceans.

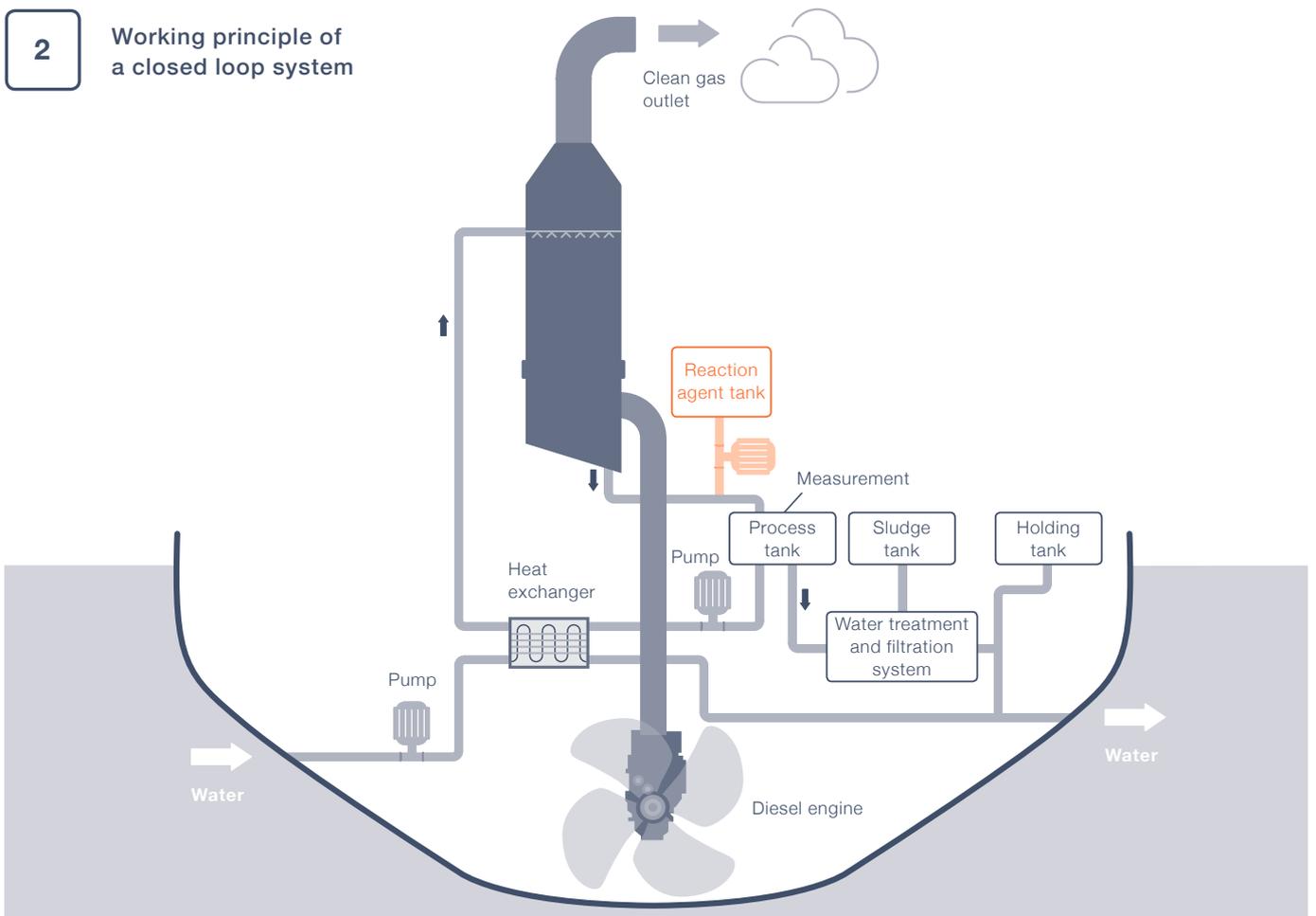
1

Working principle of an open loop system



2

Working principle of a closed loop system



Alloys and specifications

Corrosion resistant alloys for desulfurization and exhaust gas cleaning

VDM Metals designation	UNS	DIN EN	Typical chemical composition, in %	Welding consumables VDM Metals designation	UNS	DIN EN
VDM® Alloy 926	N08926	1.4529	Fe-25Ni-20,5Cr-6,5Mo-0,9Cu-0,2N	VDM® FM 59	N06059	2.4607
VDM® Alloy 31	N08031	1.4562	Fe-31Ni-27Cr-6,5Mo-1,2Cu			
VDM Alloy 31 Plus®	N08034	2.4692	Ni-29Fe-27Cr-6,5Mo-2Mn-1,2Cu-0,2N			
VDM® Alloy C-276	N10276	2.4819	Ni-16Cr-16Mo-5Fe-4W			
VDM® Alloy 59	N06059	2.4605	Ni-23Cr-16Mo-1.3Fe			
VDM® Alloy 2120 MoN	N06058	2.4700	Ni-20,5Cr-19Mo-0,5Fe-0,075N	VDM® FM 2120	N06058	2.4700

VDM® Alloy 926

DIN EN 1.4529, UNS N08926

VDM® Alloy 926 is an austenitic iron-nickel-chromium-molybdenum-copper-nitrogen alloy with an increased molybdenum content of about 6.5 % and an addition of about 0.2 % nitrogen for substantially improved resistance to pitting, crevice corrosion and chloride-induced stress-corrosion cracking. The material is firmly established for seawater and product piping systems, for flue-gas desulfurization installations in fossil-fueled power plants and for marine purification systems.

VDM® Alloy 926 also finds widespread use in applications involving chloride-contaminated media at moderate temperatures, such as sulfuric and phosphoric acids, for the concentration and crystallization of salt, and in the production of fine chemicals.

VDM® Alloy 31

DIN EN 1.4562, UNS N08031

VDM® Alloy 31 is a 6.5 % molybdenum-containing austenitic nickel-iron-chromium alloy developed by VDM Metals with excellent resistance to pitting and crevice corrosion, superior not only to conventional molybdenum-containing stainless steels but also to nickel-alloys such as VDM® Alloy 625. The alloy is resistant to pitting corrosion in seawater and offers outstanding resistance to sulfuric acid solutions, even when highly contaminated.

VDM® Alloy 31 provides outstanding performance under particularly aggressive conditions of phosphoric acid production and is probably the most cost-effective material suitable for

this kind of environment. VDM® Alloy 31 is also suitable for use in heat exchangers cooled by contaminated water such as seawater or brackish water at moderate temperatures.

Due to its extremely high resistance to local attack in acidic chloride containing solutions it is widely used in flue gas desulfurization systems where it is preferred for the spray levels and control and shut-off systems for ducts and dampers operating under demanding conditions in coal-fired power stations.

VDM Alloy 31 Plus®

DIN EN 2.4692, UNS N08034

VDM® Alloy 31 has been developed into an advanced VDM Alloy 31 Plus® version with improved fabrication characteristics but maintaining, or even improving the excellent corrosion resistance of the material. The main characteristic of VDM Alloy 31 Plus® is a lower, and therefore more user-friendly, solution annealing temperature, which was achieved through carefully balanced composition with increased nickel content and optimized addition of nitrogen. One advantage of VDM Alloy 31 Plus® over VDM® Alloy 31 is that it can be technically hot roll bonded using conventional methods and equipment.

VDM® Alloy C-276

DIN EN 2.4819, UNS N10276

VDM® Alloy C-276 is a nickel-chromium-molybdenum alloy with tungsten, which provides excellent resistance to pitting and crevice corrosion and uniform corrosion in a wide variety of chemical process media, and to reducing acid media in particular. Due to its strong corrosion resistance in pre-

dominantly reducing media, even in the presence of halogens, it has proven to be particularly effective in conquering a wide range of applications in the chemical industry.

The material has also established itself in environmental technology like flue gas desulfurization where it is used to a considerable extent in raw gas inlet, scrubbers, dampers, agitators, ducts, and so on.

VDM® Alloy 59 **DIN EN 2.4605, UNS N06059**

VDM® Alloy 59 is an advanced nickel-chromium-molybdenum alloy with outstanding corrosion resistance over a wide range of oxidizing and reducing conditions, where other nickel-chromium-molybdenum alloys have reached their limits. The material has been prominently praised in flue gas desulfurization applications where it is successfully used in areas subjected to the highest corrosive attacks, such as raw gas inlet, absorber, heat exchangers, dampers, fasteners and as welding filler metal. Its high resistance to crevice corrosion in seawater makes it a fascinating alternative to titanium as construction material of seawater cooled plate heat exchangers. Other applications include organic syntheses, run-off treatment, acid recovery systems, phosphoric acid processing and acetic acid production.

Owing to its high corrosion resistance both in oxidizing and in reducing media, its easy passivation ability and its low sensitivity to chloride contaminations in sulfuric acid solutions the alloy is an ideal construction material for multi-purpose equipment in the production of fine and specialty chemicals.

The combination of outstanding corrosion resistance and excellent workability make VDM® Alloy 59 a most suitable metallic construction material where no corrosion loss during service is allowed, e.g. in micro-channel reactors and compact diffusion-bonded heat exchangers. VDM® Alloy 59 has been established as the state-of-the-art material for all critical areas in flue gas cleaning systems. It also offers a particularly high metallurgical stability and therefore best weldability without any reduction of the corrosion resistance in the welded condition.

VDM® Alloy 2120 MoN **DIN EN 2.4700, UNS N06058**

VDM® Alloy 2120 MoN is a new nickel-chromium-molybdenum alloy that was developed with improved localized corrosion resistance and increased uniform corrosion resistance in certain acids over the Ni-Cr-Mo alloys that are currently being used. Corrosion resistance and mechanical properties were deliberately improved, while good fabrication and weldability characteristics were maintained. It is the first nickel-chromium-molybdenum alloy to contain nitrogen as an alloying element constituent. In addition, it contains the highest molybdenum content of this alloy family resulting in excellent corrosion resistance in reducing environments. The high chromium and molybdenum contents together with the nitrogen alloying result in a pitting resistance equivalent number (PREN) of about 86, surpassing all nickel-chromium-molybdenum alloys. Preferred applications are in flue gas desulfurization, sulfuric acid, hydrochloric acid, acid mixtures (even when contaminated with chlorides), and geothermal technologies.



Comprehensive customer support

Customer relationships with VDM Metals mean access to a variety of first class services – services that really make the difference.

Welding Competence Center

With our state-of-the-art Welding Competence Center we are not only capable to test different materials and welding consumables or new and unconventional materials combinations, but also to train your staff in theory and practice. Our Welding Competence Center has welding equipment for the different automated welding processes at hand. Make use of our know-how – we are happy to welcome you and your team in our Welding Competence Center.

Application Engineering

From selecting the right materials to customer requests with specific details, properties and fabrication characteristics – VDM Metals' Application Engineering team will be more than happy to provide you with prompt answers and support, relying on their technical and metallurgical background and experience in all fabrication matters of VDM Metals' materials.

Material and Corrosion Tests

Because we want to remain first-class with every product, we leave nothing to chance in terms of quality management. During their production, our materials pass numerous quality

and accuracy tests with the goal to not only meet the application's principal requirements but also the more detailed needs and specifications of our customers. VDM Metals is certified by the American Society of Mechanical Engineers and Lloyd's Register Quality Assurance (ISO 9001:2008, AS 9100 Revision C).

Research and Development (R&D)

New and more efficient processes and techniques frequently involve changes in material requirements. In cooperation with its customers, VDM Metals develops materials that perfectly satisfy these requirements. However, our aim is not just to develop new materials but also to explore hidden performance potentials in market-proven alloys which we can then qualify for new applications. Our R&D experts support the projects, sometimes right up to commissioning and start-up. The solutions that evolve find their way into new products, as well as techniques and processes.

Product Samples

If you want to test our materials, we offer product samples. Please feel free to get in touch with us.





Service Center – Reliable service to meet your needs

We understand your challenges, your markets and your business environment. Shipyard retrofit times and dry dock overhauls must be as short as possible for installation of marine scrubbers on existing and new vessels.

Rapid and reliable service is increasingly gaining importance. Furthermore, long maintenance intervals, reliability and durability of the scrubbers as well as a maintenance-friendly design bring benefits to your customers. In order to meet your needs precisely, flexibly and punctually, we operate Service Centers that offer a comprehensive stock program of corrosion resistant materials and associated services.

Sheet and plate, cut to your demands

We stock sheet and plate in sizes up to 2,500 mm x 8,000 mm (98 in x 315 in). Materials are available in thicknesses of 2 mm to 38 mm (0.078 to 1.5 in). VDM Metals meets the highest demands with tailored services. Our Service Centers are located in Europe, Asia and Australia and ensure short lead times. They are equipped with state-of-the art machinery for tailor-made cuts: We command Trumpf laser jet units and Ridder water jet units for professional cutting and handling.

We offer our plate and sheet in special dimensions, and by nesting of the different parts we take care of the best material outcome of your order to help your company save money.

During the process all parts are marked or engraved, so they can be assembled easily. A four-eyes principle during packaging ensures that your order is complete and leaves our warehouse as your construction plan requires. The scrap metal cycle is managed automatically during production. Spare parts or additional needs can be delivered quickly from our stock.

Welding consumables

As a one stop shop our Service Centers support you to simplify purchasing and procurement of sheet or plate and the appropriate filler metals. Our permanent stock of welding consumables covers a wide variety of materials in the form of welding wire, welding rods and strips, all available on short notice, within 24 hours if necessary. The welding wire can be supplied on spools/basket coils (15 kg/25 kg) or in drums (250 kg/450 kg). Welding rods for TIG welding are shipped in 5 kg boxes. Other deliveries are available upon request.

Our welding wires feature optimized cast and helix values for a smooth wire feed in automated welding processes. Our welding consumables are alloyed to extremely tight tolerances.

Integrated production

Flue gas desulfurization projects are characterized by high standards in terms of product safety and reliability, requiring partners with know-how and expertise. VDM Metals has more than 80 years of experience in designing and producing materials of the highest quality standards. The company operates production sites in Germany and the United States, covering the majority of important production steps – from melting to hot forming to cold forming.

Melting and casting

VDM Metals' nickel alloys and special stainless steels are melted in an electric arc furnace or an induction furnace and then subjected to vacuum treatment. A ladle furnace is available for secondary metallurgical treatment. Casting takes place in a vertical continuous caster or by ingot casting. In addition to the conventional technology of open melting, VDM Metals uses the technology of vacuum induction melting (VIM). The homogeneity and purity of our materials can be enhanced by electroslag (ESR) or vacuum arc remelting (VAR).

The ingots serve VDM Metals as starting material for the production of sheet and plate, strips, forgings, bars and rods, wire and welding consumables.

Sheet and plate

Sheet and plate in thicknesses of 3 to 100 mm (0.12 to 3.93 in) are hot rolled on a four-high mill, before finishing steps such as annealing, grinding, shot blasting, pickling and cutting take place. VDM Metals operates a Sendzimir reversing mill that can process hot-rolled sheet to cold-rolled sheet in widths of up to 2,500 mm (98.42 in) and thickness down to 1 mm (0.04 in).

Strips

Strips are cold rolled on four-high and Sendzimir mills. Foil can be rolled down to a thickness of 0.025 mm (0.001 in) on a special 20-high mill. Annealing, levelling and cutting equipment is available for finishing operations to meet customer specifications.



Forgings

VDM Metals' 45 MN forging press uses two manipulators and receives its feedstock from dedicated heating and re-heating furnaces. Following precisely specified procedures, bars, billets and other semi-finished products are produced.

Rods and bars

For the production of forged bars with a diameter of more than 120 mm (4.72 in) and semi-finished products, state-of-the-art turning lathes, peeling and grinding machines are available.

The production of hot-rolled and forged bars with a diameter of less than 120 mm (4.72 in) is performed with modern peeling and grinding machines. A 60-ton drawing bench is available for the manufacture of cold-drawn preci-

sion bars. Length and diameter of our rods and bars vary, depending on material and production process – in general, diameters up to 325 mm (12.8 in) and lengths up to 12 m (472 in) can be produced.

In the USA the hot rolling of round bars, flat bars, and specialty shapes is performed on either a 355 mm (14 in) or a 254 mm (10 in) hand mill. VDM Metals' finishing plants are equipped with heat treatment furnaces, pickling, shot blasting and cutting units.

Wire and welding consumables

VDM Metals produces wire in fine and ultra-fine gauges down to a diameter of 0.1 mm (0.004 in), heavy gauge and section wire as well as welding wire.

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