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Energy-saving stainless steel façades

Photo: Steffian Bradley Architects

Reducing energy consumption and improving sustainability have become primary goals for designers and building owners around the world. Designs using a second outer façade layer, which may be movable (active) or immovable (passive) can help achieve these goals. Moly-containing Type 316 stainless steel is an excellent choice for these façades because it provides design flexibility, aesthetic appeal and corrosion resistance.

If reducing energy consumption and improving sustainability were the only goals, the optimal building structure would have heavily insulated, windowless walls and would use recycled air. Of course, comfort, human health and productivity must also be considered. Balancing all these requirements while still producing beautiful buildings can be quite a challenge.

Bioclimatic designs meet this challenge by making use of the environment (for example, sun, air, wind, vegetation, water, soil and sky) for heating, cooling, and lighting. This concept is not new. For hundreds or even thousands of years we have built houses adapted to the local climate. Examples are thick-walled buildings with small windows and shutters, typical in southern Europe that keep out the summer heat and maintain the warmth in winter, or the wind towers common in hot Arab countries, which catch the wind above the house and lead a breeze into the buildings.

But bioclimatic designs have been forgotten over the years with the widespread use of central heating and air conditioning. The necessity of saving energy has lead to a renewed appreciation of these design principles. These new designs also seek to connect building occupants with their surroundings through a maximum amount of natural lighting and green spaces such as atriums, courtyards, landscaping and green screens.

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Bubbling up with stainless

Fresh clean drinking water is something we all expect, including the citizens of Fairfax County near Washington, DC, USA. The local water authority strives to both meet these expectations and enhance the environment. Their latest project will bubble oxygen gas into the Occoquan water supply reservoir. This will achieve better oxygen distribution within the reservoir, improving its environmental, aquatic and recreational value. The project will also produce better manganese control and therefore better water quality for domestic consumption. Moly-containing Type 316 stainless steel components are an important part of the equipment required for the project.

Exciting new things are bubbling up at the Occoquan Reservoir in Fairfax, Virginia, where molybdenum stainless steels are helping to make drinking water safer and better than ever. Dale Kovach, Manager of Construction for Fairfax Water, offered a brief overview of both the project itself and molybdenum's crucial role in it.

Stratification and water quality

A dam in the Occoquan River in southeastern Virginia has created the Occoquan Reservoir with a current capacity of around 31 million cubic meter. During summer months, the reservoir water can separate into three temperature regions and the bottom of the reservoir becomes anaerobic (having low concentrations of dissolved oxygen, or DO). The three temperature regions are the epilimnion (warm top), the hypolimnion (colder bottom) and the thermocline (middle region). Anaerobic conditions result when the colder bottom becomes separated from the warmer top. This can suppress the fish and plant populations that require oxygen for life, and trigger the release of organic compounds containing manganese and phosphorous from ground sediment, further degrading water quality. These minerals affect the taste and odor of drinking water and tend to accumulate as black or orange build-up on plumbing fixtures. As water temperatures decline at the end of summer, the epilimnion cools and its water moves down into the hypolimnion. This stirs and mixes the low-oxygen water throughout the reservoir and restores the oxygen content of the hypolimnion. Fairfax Water aims to preserve a minimum DO level of 5 mg/L, the minimum needed to prevent the release of the organic compounds that affect water quality. This was previously achieved by a "destratification" system that used air compressors to mix oxygen-rich water from the top with the oxygen-depleted water, similar to an aeration pump in a fish tank. However, recent studies by Fairfax Water found that the system added only about half the required oxygen.

Hypolimnetic oxygenation systems and molybdenum's key functions

The destratification system is being replaced by a "hypolimnetic oxygenation system" (HOS), which can enhance natural aeration and prevent mineral release without having to mix the entire water →

Content

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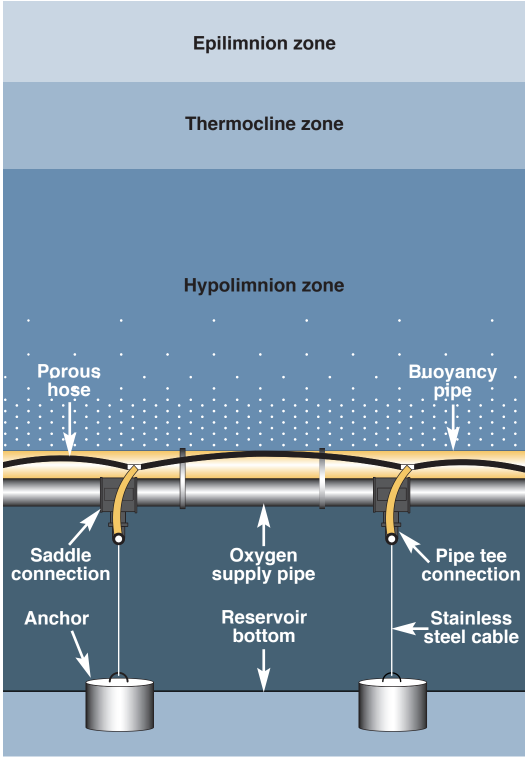


Arrangement of major components of the oxygen bubbling system, not to scale.

The Occoquan Dam project includes major dam rehabilitation as well as installation of the water quality improvement system. Photo: Fairfax County Water Authority

column. The HOS system aerates only the hypolimnion waters that are susceptible to water quality problems due to low DO, since the warmer waters of the epilimnion layer are naturally aerated. The system "works with Mother Nature" by bubbling pure oxygen from a porous hose into the water during the warmer months. The porous hose (also called "line diffusor") is positioned 20 meters below the surface, just above the floor of the reservoir with the help of a buoyancy system. The buoyancy pipe is tied to numerous anchors, allowing it to float a specific distance above the reservoir bottom. When the buoyancy pipe is full of air, the line diffuser floats, and when flooded with water, the diffuser sinks. The system is so effective that a single 800-meter long line diffuser, producing a curtain of rising bubbles, can do the job. To put it simply, the HOS offers more "bang for the buck" than the traditional method, increasing both the quality and quantity of treated water.

Fairfax Water stores liquid oxygen for the system in a 49 cubic meter Type 304 stainless steel vacuum-enclosed tank. The liquid oxygen is carried through 30 meters of Type 316 stainless steel pipes and valves to two dedicated vaporizers which convert the liquid oxygen into gas. The 110-meter pipeline that carries the gas to the line diffuser and all the required valves are made of Type 304 stainless steel. Although other pipe materials can be used for projects of this kind, Mr. Kovach explains that Type 316 stainless steel was chosen for handling the liquid oxygen due to its strength and high melting point compared to other materials. These are key advantages in this application because liquid oxygen supports combustion. Stainless steel provides a margin of safety in an emergency and ensures safe, quality performance under normal operating conditions. Another key advantage of moly-grade stainless steel over competing materials is its resistance to atmospheric and aqueous corrosion, important because the gaseous oxygen pipe will be submerged in water and mounted to the concrete dam. Fairfax Water opted for Type 316 supports and anchors because they will not corrode and discolor the dam face.

Molybdenum containing stainless steel pipe functions somewhat like blood vessels in this application, dependably carrying essential materials to their destinations. Type 316 stainless helps to ensure the new HOS will be reliable and long lasting, and that the drinking water of over 1 million Fairfax Water customers will be cleaner and better tasting than ever. (dk)

The Occoquan Dam and lower reach provide plenty of action at times of high water flow. Photo: Fairfax County Water Authority

Molybdenum disulfide – a great lubricant

Molybdenum disulfide is the preferred lubricant in many applications. It is used as a dry powder, a suspension in oils or greases, and an additive in plastic composites. It provides for the smooth functioning of machines, which translates into substantial world-wide material and energy savings.

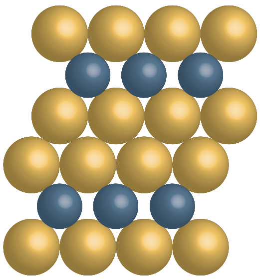
In 1860s Colorado, gold-rush miners lubricated wagon-wheel axles with molybdenum disulfide, prompting a writer of the time to say about the material, "It feels much like soap, and its rubbing against solid bodies renders them slippery." [1]

A lubricant reduces friction and wear between moving surfaces in contact with one another by producing a "slippery" film that separates them. Liquid oils and greases are the most common basic lubricants. Molybdenum disulfide is used as an additive to improve the performance of lubricants under demanding conditions. For example, high pressure may squeeze a liquid lubricant film out, but molybdenum disulfide added to the liquid lubricant remains like a coating on the surfaces to provide continued lubrication. Molybdenum disulfide may also be used alone as a dry powder, or as an additive to composite materials.

Molybdenum disulfide is widely used as a dry lubricant in bearing applications. Photo: istockphoto/frankright

Molybdenum disulfide structure and lubricity

Molybdenum disulfide is a grey solid with a slippery texture like graphite. It is extracted from the mineral molybdenite, which contains about 0.25% molybdenum. It is marketed by many manufacturers as dry powder; standard grades have maximum particle sizes of 190, 36 and 7 microns. Lubricant grades have a molybdenum disulfide content greater than 98%.



Molybdenum disulfide with its layered atom structure. The blue spheres represent molybdenum atoms and the yellow spheres sulfur atoms. Under a sideways force the S-S layers slide before the S-Mo layers break or slide. Friction is much reduced.

Molybdenum disulfide owes its lubricity to its structure – layers of molybdenum atoms stacked between layers of sulfur atoms. These SMoS layers are stacked with the sulfur atoms of each SMoS layer in contact, but they are not chemically bonded. This structure has been compared to a deck of cards, each card representing a SMoS layer. The layers can support a downward force, but they slide easily when a sideways force is applied. Particles of molybdenum disulfide form an adherent coating on metal surfaces that acts as a lubricating film between them. When the surfaces move relative to each other, sliding occurs between the SMoS layers and not the metals, reducing friction.

As a dry lubricant

The dry powder is applied to clean, degreased metal surfaces by brushing or by applying a dispersion of the sulfide in a volatile solvent. Molybdenum disulfide is typically used as a dry lubricant in difficult and extreme applications. Common uses are the break-in period of engines, metalworking operations such as pressing and bending, and brake linings.

Dry lubricant powder applications – Because it is a solid, molybdenum disulfide retains its lubricity in a vacuum. It is useful over the temperature range of liquid nitrogen (-196°C) to 1200°C in a vacuum or an inert atmosphere. It oxidises in air above 400°C, losing its lubricity. It is non-volatile and does not outgas, so it is an ideal lubricant for use in space applications. Space vehicles use bearings with thin films of molybdenum disulfide sputtered on ball or roller cages.

Another high-vacuum application is for the moving parts in **particle accelerators**, for example, the accelerator at CERN, Geneva. Molybdenum disulfide does not emit particles and is stable under nuclear radiation, so it is the preferred lubricant for gears in **gas-cooled nuclear reactors** where it will not contaminate the helium cooling gas.

Molybdenum disulfide is used to lubricate the moving parts of **jet engines**. An important attribute in this application is that it is non-flammable.

As a solid or in solid composite applications

Self-lubricating composites contain finely-divided particles of molybdenum disulfide suspended in various plastics. They are used for gears, pulley sheaves, sprockets and custom parts. They can provide excellent performance as thin coatings for parts that have tight tolerances. Applications include **printers, scanners, jet engine parts** and components that are inaccessible after assembly.

Manufacturers of parts for the auto industry use molybdenum disulfide coatings on parts like **piston rings**. In this case, molybdenum disulfide is formed in situ from a molybdenum compound instead of being applied as molybdenum disulfide. In a newly-developed process, the US Department of Energy has demonstrated a self-lubricating coating →

by exposing a titanium alloy to a mixture of molybdenum hexafluoride and other gases. The resulting coating contains grains of molybdenum disulfide dispersed in titanium nitride. Tests show that the composite coating's coefficient of friction is only one third that of a pure titanium nitride coating.[2]

As an additive in oils and greases

The largest commercial use for molybdenum disulfide is as an additive to oils, emulsified oils, and greases. Such "sulfurized lubricants" are considered to be premium lubricants used under heavy loading conditions, and are marketed by many specialty companies.

Automotive applications – In this large market many proprietary sulfurized oil and grease formulations are available and many claims are made, for example:

- Molybdenum disulfide incorporated in a crankcase oil, replenished at six month intervals, will maintain maximum engine protection against dry and cold starts, wear and oil contamination.
- Molybdenum disulfide in the oil reacts with hot metal surfaces.
- A solid molybdenum disulfide film plates out on the surface.
- An engine so treated with molybdenum disulfide is said to be moly-plated.
- Molybdenum disulfide plating an engine provides protection two to three times that of oil alone and doubles the life of an engine.

While we should be wary of exaggerated claims, substantial benefit cannot be denied.

General transportation – Molybdenum disulfide helps with energy conservation in transport by reducing frictional losses in the engine and drive train. In fact, every time a lubricant is used in a machine the net result is a reduction in energy cost, which accumulates to being a significant factor in terms of worldwide energy costs. Improvements of 3% in engine efficiency and up to 4% in final drive efficiency are possible.[3]

The lubricating qualities of molybdenum disulfide and its resistance to high heat make it a preferred additive to race car engine oils and other lubricants. These lubricants reduce oil drag and prolong cylinder compression life. Photo: istockphoto/mevans

Metal working – The machining and shaping of metals requires lubricants that are effective under extreme pressure. High-performance sulfurized lubricants are standard in this large and important application.

Summary and a word of caution

Molybdenum disulfide is an effective and versatile lubricant providing for the efficient operation of many high-performance machines. Its wide use produces many economic and sustainability benefits to our society. Proprietary lubricant formulations are available, but some carry claims that might not be substantiated. Full descriptions, applications, and limitations are available on manufacturers' web sites. (pm)

1 Molybdenum Disulphide Lubrication, A.R. Lansdown (Ed.) Elsevier, 1999, p.3
2 http://www.ornl.gov/info/press_releases/get_press_release.cfm?ReleaseNumber=mr19950329-01
3 E.R. Braithwaite and A. B. Greene, A Critical Analysis of the Performance of Molybdenum Compounds in Motor vehicles, "Wear", 1978, 46,p. 405-4

Wind turbines are enormous machines weighing over 200 tons. They have large bearings subject to very high forces. These high forces and the relative inaccessibility of wind turbines place high demand on their bearings. This in turn requires special lubricants containing molybdenum disulfide. Photo: istockphoto/Baxternator

Skiers go farther and faster when molybdenum disulfide is present in their ski wax because it offers better glide and durability than graphite. Photo: istockphoto/technotr

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Energy-saving stainless steel façades

Stainless steel plays a large role in many of these bioclimatic projects because of its longevity and low maintenance requirements. Many of these projects are in more corrosive locations with industrial pollution or coastal salt exposure. Since the designs inherently create sheltered areas that are unlikely to be washed by rain, more highly alloyed molybdenum-containing stainless steels are a logical choice, given their improved resistance to corrosion.

Double façade technology

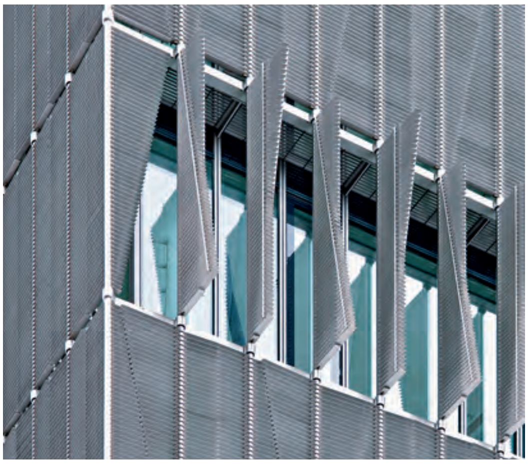
The double façade is a typical bioclimatic design element. Exterior building walls are no longer simple climate defense mechanisms. Two façade layers are used: an insulating wall, and a second "shading," or sheltering, layer. The inner wall is shielded from weather by the outer layer. Windows in the inner wall are operable and sometimes computer controlled to maximize natural ventilation.

For the outer wall, a variety of technologies are used, including louvers, woven mesh, perforated screens and green (plant) screens. They may **actively** change with varying conditions, or remain **passively fixed**. This great diversity of design options makes the bioclimatic style equally appropriate for state-of-the-art buildings or low technology/low maintenance designs.

Active second façade systems

Hybrid systems, a type of active second-skin façade, employ an operable shading system over insulated glass. The façade may be the outermost wall, or between the inner and outer glass layers, which can be from 0.2 to 2 meter apart, and incorporate integrated sunshades and natural ventilation.

Computer-controlled mechanical operating systems that work with the building's heating and cooling systems make it possible to respond dynamically to varying conditions. By adjusting to the sun's trajectory, they maximize the benefits of solar radiation



The ThyssenKrupp Quarter corporate campus uses Type 316 stainless steel exterior sunscreens in varying styles to actively adjust to seasonal and weather conditions to reduce energy requirements. Photo: ThyssenKrupp AG

while minimizing heat gain. Although active systems are highly adaptable, they are not suitable for all applications, since energy is necessary to operate these assemblies, and sensors and mechanics require maintenance. The following are several examples of highly successful active systems.

ThyssenKrupp AG Headquarters – TKQ architect consortium, JSWD Architekten and Chaix & Morel teamed up with ThyssenKrupp AG to design their new seven-building corporate campus in Essen, Germany. All of the buildings are simple glazed structures, but their unique second façade sets them apart. The buildings are wrapped in automated sunshade systems consisting of horizontal and vertical slats or custom perforated sunscreens. These active systems have moveable Type 316 (UNS S31603) stainless steel slats, which save energy by automatically adjusting to changing conditions. This system, when used in combination with natural ventilation, eliminates the need for air-conditioning. German Sustainable Building Council (DGNB) has awarded the project a Pre-certificate in Gold based on the new German Certification for Sustainable Buildings. Energy requirements are expected to be as much as 20 to 30% below statutory requirements.

Council House No. 2 – Melbourne, Australia's multi-award winning, ten-story Council House No. 2 achieved the Green Building Council of Australia's highest Green Star 6 rating. Compared to typical construction methods, it uses 85% less electricity. Since half the energy consumption for typical Melbourne buildings is for traditional air conditioning, this is a great reduction. Additionally, the Council House uses 87% less gas and 72% less potable ➔

Plant screens were used along the balconies on the north side of Council House No. 2 and over the roof deck to shelter them from sun. Photo: Ronstan Tensile Architecture

water, and also reduces CO_2 emissions by as much as 60%. These great statistics are achieved through the use of active and passive sunscreens, conductive cooling of the ceiling, and also natural ventilation.

The west facing public façade is comprised of timber slat sunscreens, supported by a lightweight Type 316 stainless steel tension cable system that allows them to be pivoted in response to the time of day and angle of the sun. On the north side of the building, passive green plant screens were used on the sides of balconies to screen low angle sun and filter glare. The whole structure, which is supported by a Type 316 mesh and tension cable system, extends over the roof and provides an arbor-like sunshade for the rooftop terrace.

Passive second façade systems
Second layer systems that do not move or adjust themselves to climatic conditions are termed passive systems. They use lightweight framing to support woven mesh or perforated panels, which allows the designer to anticipate changing climatic conditions by varying the distance between the inner insulated wall and the exterior hybrid second skin. These sunshade systems can allow designers to create seamlessly curving geometric and other shapes, which can dramatically change the appearance of a new or existing building at a much lower cost than installing an undulating insulated curtain wall. Passive systems also avoid the maintenance requirements of automated systems while still improving energy efficiency, and are suitable for any environment.

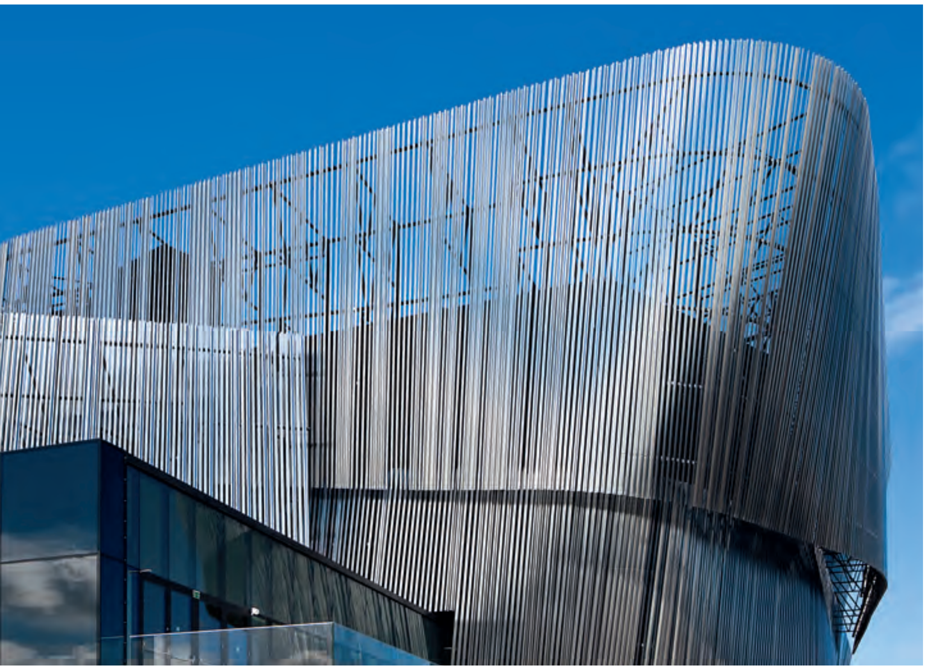
41 Cooper Square – 41 Cooper Square is a new 16,300 m^2 university building at the Cooper Union, which was completed in 2009. It is the first US Green Building Council LEED-certified educational building in New York City, and received a US LEED Platinum rating in recognition of its innovative design. A seemingly simple glass and aluminum building was wrapped in a curving second facade of perforated Type 316 stainless steel panels. This semi-transparent layer gives the building a dramatic sculptural presence with areas of light and shadow. Functionally, the second layer reduces thermal radiation in the summer, shields the inner wall during winter, and allows natural light to enter. Additionally, seventy-five percent of the building's regularly used interior spaces are lit with natural daylight. When combined with other design elements, the stainless steel panels help to reduce the building's energy requirements by 40%, relative to a standard building of its type.

Guangzhou 2nd Children's Activity Center – The Guangzhou 2nd Children's Activity Center (cover picture) in China provides teaching and performance space for after-school and weekend arts education for primary and secondary school students. Designed by Steffian Bradley Architects (SBA) and completed in 2006, this 42,735 m^2 concrete and glass building has a capacity for 20,000.

The perforated Type 316 screens around 41 Cooper Square give it a sculptural appearance while reducing the building's energy consumption. Photo: Iwan Baan Studio

The exterior's dramatic and seamless compound curves were created by a Type 316 stainless steel mesh metal panel system, which eliminates the need for air-conditioning in common spaces, substantially reducing energy requirements. The woven mesh also maximizes natural light inside the building, creating a distinctive identity as well as excellent energy savings.

Stockholm Congress Centre – Designed by White Arkitekter of Stockholm and completed in 2011, Sweden's new Congress Center, which is expected to receive green building certification, is located along the waterfront in the heart of the city. The contoured, ribbon-like, softly reflective pieces of stainless steel hover away from the structure, lending it a striking, undulating appearance, and excellent energy efficiency. →



Contoured, ribbon-like, softly reflective pieces of stainless steel hover away from the Stockholm Congress Centre, creating its distinctive appearance. Photo: Outokumpu

The passive sunscreen, which angles outward from the wall, used 3,500 Z-shaped duplex 2205 (UNS S32205) stainless steel sections, 3 to 16 meters in length with a semi-reflective matte finish. The screen angle reflects away summer sun while still allowing natural light to enter. Since the seasonal angle of the sun changes in winter, sunlight passes through the wall to passively heat the building.

Conclusions

Successful sustainable bioclimatic design requires materials that can last the life of the structure or project. Many of these designs inherently create sheltered environments that are visible from inside the building. These areas naturally are more corrosive because the washing action of wind and rain is not available. Thus, corrosion-resistant molybdenum-containing stainless steel is often the best choice for bioclimatic second-façade architecture. As the most corrosion resistant of the readily available architectural metal options, it contributes not only to the functionality and efficiency of these structures, but also helps lend them their striking appearance. Molybdenum may soon be bringing cleaner, greener buildings to a corner near you. (ch)

Atomistically molybdenum

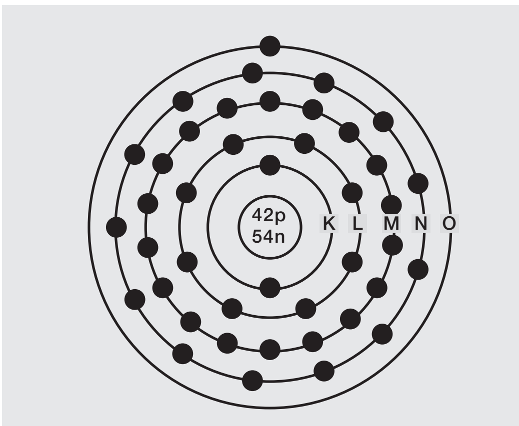
Molybdenum is a transition element with an atomic number of 42 and an atomic mass of 95.96, located in Group 6 of the periodic table. While the preceding sentence may not make much sense to an uninitiated reader, a good chemist or physicist can tell you more about molybdenum than you might imagine, just by knowing this much. It is a fascinating picture.

Molybdenum is used in a wide variety of ways: as an alloying element in other metals like iron, nickel, and titanium; in chemicals like catalysts, lubricants, corrosion inhibitors and agricultural chemicals; and even in its pure state as a metal. The unique properties that allow it to be used in so many ways are directly related to its atomic properties and the ways molybdenum atoms interact with one another and other atoms. To understand why molybdenum behaves this way, we have to understand the nature of an atom – the smallest quantity of any element that is still that element.

Atoms

The atom's basic building blocks are **protons**, **neutrons** and **electrons**. **Protons** are heavy particles (1.6726×10^{-27} kg) that carry a single positive charge. **Neutrons** are only 0.14% heavier than protons (1.6749×10^{-27} kg) and are electrically neutral, while **electrons** are very light particles (9.1094×10^{-31} kg, or 1/1836th the mass of a proton) that carry a single negative charge. A simple atomic model comprises a dense core (**nucleus**) of neutrons and protons and **shells** that contain electrons, which surround the core.

The number of protons in the nucleus is the atom's **atomic number**. This number tells us the atom's elemental identity. A given element may exist with various numbers of neutrons in the nucleus. These variants are called **isotopes**, from the Greek iso (same) and topos (place). They still occupy the same place in the periodic table because they all ➔



Schematic picture of the molybdenum atom showing the electron shells surrounding the nucleus.

have the same number of protons. For an atom to be neutral, its electron number must equal its proton number. If the atom has more or fewer electrons than protons, it is called an **ion**. The **atomic mass** of an atom is the sum of all its proton, neutron, and electron masses, but the sum of its neutron and proton masses is a very good approximation to the atomic mass.

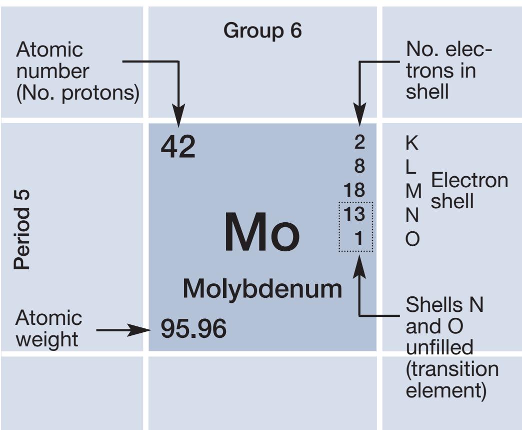
Electrons fill their shells according to well-defined rules that permit some elements to have the shell immediately below the outermost shell (the penultimate shell) to be only partially filled. Elements with partially filled penultimate shells are called **transition metals**.

Each element's arrangement of protons, neutrons, and electrons is unique. The arrangement determines how the element behaves chemically. It also relates directly to the physical properties observed in bulk samples of the element, and to the element's nuclear stability. This short discussion focuses primarily on chemical behavior.

The periodic table

The **periodic table**, devised by Dmitri Mendeleev in 1869, displays the elements in an organized fashion that illustrates their chemical nature. Many other scientists have proposed alternative versions, but nearly all show the elements arranged in a two-dimensional grid. The table arranges elements in rows with atomic number increasing from left to right and top to bottom (see figure). Rows are designed so columns contain elements having similar chemical characteristics. Molybdenum and its companions are located in the center of the table within a group called **transition elements** – atoms with incomplete penultimate electron shells.

An element's atomic mass and number of electrons are its most important characteristics. This arrangement plays a large part in determining how the atoms bond together and react with atoms of other elements. The periodic table gives a trained chemist a perspective on each element at a glance. An excellent interactive periodic table is available at http://www.ptable.com.



Molybdenum's place in the periodic table – important descriptors

Period \ Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H																	He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg											Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	**	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uuo

* Lanthanide series; ** Actinide series; Transition elements blocked in yellow

Simplified periodic system of the elements. For simplicity, the Lanthanide and Actinide series are omitted.

The atomic makeup of molybdenum

Protons – The enlarged illustration (see figure below) gives a closer look at molybdenum's place in the periodic table. The square's upper left corner displays molybdenum's atomic (proton) number 42.

Neutrons – Adding neutrons to the protons in the molybdenum nucleus gives molybdenum's relative atomic mass (95.96 unified atomic mass units) which is in the lower left corner. The number of neutrons is variable, so several isotopes of molybdenum exist in nature. This is one reason why the atomic mass is not a whole number.

Electrons – The molybdenum atom contains 42 electrons to balance the proton charge. The square's upper right corner shows how molybdenum's electrons fill their shells. Thirteen are in the N shell, which chemists know has a capacity of eighteen. Since the O shell contains an electron, the (penultimate) N shell must be unfilled. Hence, molybdenum is a transition metal. The periodic table's construction places all the transition metals together. This makes it easier to identify them and helps us to understand how they react with other elements. These partially filled shells enable molybdenum to interact with other metals and non-metals in many ways.

The molybdenum atom and chemical properties

Molybdenum through its unfilled outermost electron shells can lose and gain electrons. This ability, to transfer and share electrons, is closely linked to compound formation, which is why molybdenum is chemically versatile. Molybdenum is chameleon-like, forming alloys with metals, and compounds with, for example, oxygen, sulfur, chlorine and carbon compounds. This versatility is why molybdenum is important in catalysis, biology and human health, as previous MolyReview articles have discussed.

Summary

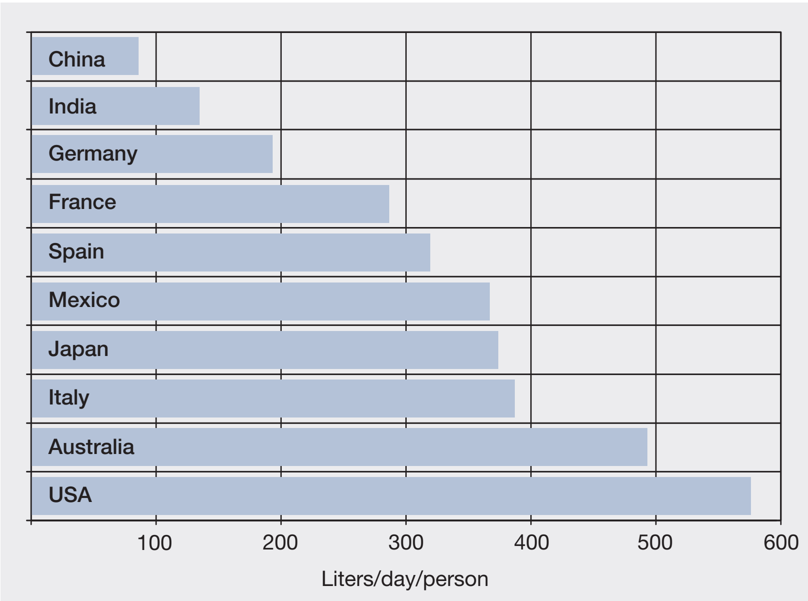
The structure of the molybdenum atom provides insight into why this element finds unique applications in chemistry, biology and technology. A brief discussion cannot do justice to the exciting world of the molybdenum atom. (jp)

Water – our most valuable resource

A great challenge facing the world today is how to meet future fresh water needs. More fresh water will be needed but our resources are limited. Conservation will help, but the only real solution is to make fresh water from seawater. Moly-containing stainless steels play an important role in the desalination plants used to meet this challenge.

One day when one asks for a glass of water, will the answer be "There is none"? We hope not. There is no doubt that clean fresh water is essential for healthy living and thriving communities. What would we do without it? Except for the commonly quoted fact that 70% of the earth's surface is covered by water, few of us know much about the statistics and trends related to this vital resource. For example, did you know:

- 97% of the earth's water is too salty for human consumption.
- Less than 1% of our accessible water is fresh and safe.
- By 2025 the earth's population is expected to increase by 1 billion people, greatly increasing fresh water demand.
- With fixed supply and consumption increasing at its current rate, we will be consuming all available fresh water by 2025.
- Currently about 40% of the population, or 3 billion people, live in water-scarce regions.
- According to the United Nations, 1.1 billion people now have no access to a reliable water supply, and 80% of the disease and deaths in developing countries are associated with unsanitary water.
- Agriculture consumes 75% of our fresh water resources to produce 40% of our food supply.



Summary of the per-capita water consumption for various countries. Source: Data360

Questions about water supply

The above statistics and projections produce two fundamental questions. Where will the needed extra supply of fresh drinking water come from? Where will the needed extra agricultural water be found? Frighteningly, at our current per-capita consumption level, the water supply will not be able to sustain the expected population by 2025. The solution to this problem will require a multipronged approach involving conservation, reuse, and development of new fresh water sources.

Reducing water consumption

Per-capita residential water consumption varies substantially depending on cost and availability. In the United States, the average daily consumption per person is 575 liters compared to 193 liters in Germany. This demonstrates that people can get along with less water if necessary. Conservation works in places where water is readily available and where poor usage habits have lead to high consumption. It is far less likely to succeed where consumption is already low, such as in arid regions. Unfortunately, the population growth tends to be high in exactly these arid third-world countries where the water-saving potential is low.

Altering agricultural practices offers the greatest potential for conservation because of the large amount of water used and the inefficiency of its use. Currently, worldwide irrigation efficiency is only around 35%, so even small improvements in efficiency will yield large savings because of the large usage. Any solution to our pending water problem must include more efficient irrigation methods.

Using wastewater (water reclaimed from one application) for another application can stretch scarce water resources. The most common example is using treated sewage water to irrigate golf courses and other landscape applications. Reclaimed waters are also used to supplement in-stream flows during dry periods, for wetland enhancement, and for coastal ground water injection to minimize saltwater. Our reuse of wastewater must increase greatly in the coming years. This will include the reuse of municipal wastewater as potable water, even though we don't like to think about this possibility.

Producing new fresh water – desalination

The only way to increase our supply of fresh water is to produce it from an abundant source, seawater. We can do this by various desalination (desalting) processes. Today desalination is widely performed by either thermal distillation technologies (TD), or reverse osmosis (RO). Thermal distillation ➔

evaporates seawater and collects the condensed vapor as fresh water. Reverse osmosis passes seawater through a special membrane filter that removes the salt.

Global desalination capacity has increased exponentially since the early 1960s, and this rapid growth is expected to continue. There are about 14,400 desalination plants in operation around the world, having a total daily capacity of 62 million cubic meters of fresh water, or 16.3 billion gallons. This may seem like a lot of water, but in reality it is only ten times the amount of fresh water provided daily by the Fairfax Water Authority to its 1,700,000 customers (see the article on page 2). You might say, “A drop in the bucket” compared to anticipated future needs.

Molybdenum plays a critical role in desalination technology. The most cost-effective materials of construction for desalination plants are molybdenum-bearing stainless steels because molybdenum provides excellent corrosion resistance in seawater. Commonly used grades for brackish water RO plants and for distillation chambers in thermal seawater desalination plants are Type 316L (S31603), 317L (S31703), and 2205 (S32205). These grades contain between 2 and 3.5% molybdenum. The more highly alloyed grades such as the 6% Mo super austenitic and 2507 (S32750) super duplex stainless steels are commonly used for high-pressure piping applications in seawater RO plants. These materials have an excellent performance record in both types of plants.

Summarizing the future for molybdenum

Statistics speak for themselves regarding future world needs for fresh water and new desalination plants. Every TD plant uses a large amount of molybdenum-grade stainless steel plate and tubing, while every RO plant uses a large amount of moly-grade stainless steel pipe. Mo-grade stainless steels have already established themselves in an existing market with a tremendous future growth potential. As our natural fresh water resources become increasingly scarce, molybdenum will play an ever-increasing and vital role in efforts to increase our fresh water supply. (jf)

Solid 2205 duplex stainless steel evaporators used in a TD plant in Mellitah, Libya. Photo: Reggiane

The Fujairah seawater RO plant in the United Arab Emirates, showing its 6% Mo stainless steel piping. Photo: Degremont

Stainless steels commonly used in brackish water treatment plants and seawater desalination plants (nominal compositions in weight %, balance iron)

Grade	UNS No.	EN No.	C (max.)	Cr	Ni	Mo	N	Other
Austenitic Stainless Steels								
316L	S31603	1.4404	0.03	17	11	2.1	–	–
317L	S31703	1.4438	0.03	18	12	3.1	–	–
904L	N08904	1.4539	0.02	19.5	24.5	4.5	–	–
6% Moly grades	S31254	1.4547	0.02	20	18	6.1	0.20	Cu - 0.70
	N08926	1.4529	0.02	19.5	24.5	6.1	0.20	Cu - 0.70
	N08367	–	0.03	20.5	23	6.1	0.20	–
Duplex Stainless Steels								
2205	S32205	1.4462	0.03	22	5	3.3	0.16	–
2507	S32750	1.4410	0.03	25	7	3.7	0.27	–

IMOA AGM 2011

"The Steel City" of Pittsburgh made an excellent backdrop for IMOA's 2011 AGM, thanks to generous host, Thompson Creek Metals. Home to many titans of industry, like Andrew Carnegie and George Westinghouse, Pittsburgh once produced over half of America's total steel output, more than all of Europe combined. Today, the city is as well known for its educational, medical and cultural institutions as it is for steel, and it is also a haven for financial and high-tech industries. Over 130 delegates from 57 companies and 21 countries took advantage of the opportunity to visit Pittsburgh to meet and discuss issues of concern to the molybdenum industry.

A full social program included gala dinners at the impressive Phipps Conservatory and the spectacular "Music Hall Foyer" of the Carnegie Museum. A record number of companies were in attendance and, welcoming members and guests, IMOA President Mark Wilson noted that such high levels of participation were the essence of an industry association.

Expert speakers from both academia and industry gave presentations addressing markets, economy and sustainability. Appropriate to the location, there were papers on developments in specialty steels, advanced high-strength steels and superalloys. New research in the field of catalysis, funded in part by IMOA, was also featured and a paper on Health, Safety and Environment topics demonstrated IMOA's approach to regulatory matters: well-designed, sound scientific investigation and dialogue with relevant authorities. Members agreed that it was another successful and informative IMOA meeting.

IMOA's next AGM will be held in September 2012 in the Spanish capital, the vibrant and welcoming city of Madrid.

Pittsburgh presents a beautiful sight when viewed at dusk from Mount Washington. Photo: istockphoto.com/Andy445

Symposium on Mo in high performance steels

The first Taiwan Symposium on "Fundamentals and Applications of Mo and Nb Alloying in High Performance Steels" was held November 7–8, 2011 in the Taiwanese capital of Taipei. The symposium was jointly organized by IMOA, CBMM, NiobelCon, China Steel Corporation (CSC) and National Taiwan University (NTU).

Leading research experts from both academia and industry gathered to exchange ideas on the innovations in steel development necessary to improve energy conservation, reduction of CO_2 emissions, and other serious sustainability challenges facing today's steel-related industries. More than 80 delegates gathered to hear 15 presentations from internationally renowned experts, focusing on "Metallurgical Fundamentals" and "Product Applications" of high-performance steels alloyed with Mo and Nb. Of particular interest were the synergies achieved by alloying with these two elements and other micro-alloy constituents, which together create a more profound effect on the host metal's properties than each element's individual effect.

Line pipe, automotive, and structural applications provide excellent examples where these effects lead to enhanced strength and toughness for a variety of service conditions. These better properties save weight and improve performance and safety in end-use applications. Alloying can also be cost-effective when processing and quality considerations are evaluated.

The symposium was judged a great success by its participants and organizers, who are keen to repeat the format in the future. The proceedings of the symposium will be available on the IMOA website, www.imoa.info.