HISTORY CORNER

A SHORT HISTORY:

VACUUM SEALING—GREASES, OILS, CEMENTS, ELASTOMERS, AND METALS

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The first use of a cement that relied on its ability to "hold" a vacuum was the use on Gasparo Berti's (Italy) water barometer (c. 1641) where a glass "flask" was cemented to the top of a long (~11 m) lead pipe that stood in a barrel of water[1]. Both the top of the flask and the end of the pipe in the barrel of water had a valve. Berti closed the valve in the barrel, completely filled the pipe and flask with water from the top, closed the valve at the top, and then opened the valve at the bottom. The water column in the pipe fell to the level dictated by the ambient atmospheric pressure. Berti then closed the valve at the bottom and measured the height of the water column in the lead pipe by a "sounding line" through the upper valve.

In 1644, Evangelista Torricelli (Italy) demonstrated the mercury barometer using a closed-end glass tube and creating a "Torricellian vacuum" above the mercury column[2]. The glass tube allowed visual observation of the height of the mercury column. The Torricelli barometer did not use any cements but later, when the Florentine scientists began performing experiments in the Torricellian vacuum, they probably cemented chambers to the top of the mercury tube to make larger, more accessible experimental chambers[a].

Otto von Guericke (Germany) developed the first mechanical piston-type "air pump" (vacuum pump) in the 1640s. His air pump was based on the piston-type (syringe) water pump used at that time[3]. The vacuum pump required moving seals and those were probably leather greased with animal fat. In 1654, von Guericke presented his famous Magdeburg hemispheres demonstration. In von Guericke's account (1672) of the 1654 Magdeburg hemispheres demonstration, he stated that the seal between the two metal hemispheres was made with leather treated with a wax and turpentine mixture[4]. Otto von Guerick's work was first reported by Caspar Schott in 1657[5] and this account spurred interest in the scientific community, including the interest of Robert Boyle.

Robert Boyle (England) was the first to make an experiment in a glass vacuum chamber sealed to a metal baseplate circa 1660. He placed a Torricelli-type manometer in the glass chamber and evacuated the chamber to ~0.25-in. of mercury (6 Torr) using a piston-pump designed and built with the aid of Robert Hooke (then Boyle's assistant) ("vacuum within a vacuum")[6,7]. This was the first "vacuum system" with the experimental chamber separate from the vacuum pumping system and with a vacuum gauge to measure the pressure in the chamber. The manometer tube was taller than the chamber was high, so a hole was made in the top of the glass bell jar and the manometer tube sealed to the bell jar—this was probably the first use of a vacuum feedthrough. The cement mixture was not specified but Boyle used a mixture of "pitch, resin and wood ash" that was "well incorporated" in the construction of the vacuum system. Boyle reported on a number of experiments in vacuum in 1660[6,7]. The "piston" type vacuum pumps (solid or mercury[8,9] pistons) and mercury manometers were to remain the principal types of vacuum pumps and vacuum gauges for roughly the next 200 years.

Waxes and Cements

In his review of mercurial pumps published in 1888, Silvanus Thompson, FRS (England) gave an account of the "cements" then in use[8]. To quote:

> "On Vacuum cements—Appendix III—For cementing joints, in cases where a fused joint in the glass is not convenient, various recipes have been given. None are equal, however, to a real fused joint. A mixture of resin (clear colophonium) and bees'-wax in about equal

[a]The first successful experiment in vacuum was by Vincenzio Viviani in 1644 who mounted a bell in the Torricellian vacuum and showed that the ringing was muted when under vacuum. Viviani was a pupil of Torricelli and a disciple of Galileo.

> parts has been employed by Crookes, Moss, Giming, and others. It should be applied warm, and the parts to be joined should be well-warmed previously. If there is a greater portion of resin it becomes brittle. India[b]—preferably good black unvulcanized gum-rubber—warmed, so as to become sticky, also makes a fair cement. Rood suggests a mixture of 96 parts of Burgundy with 4 of gutta-percha[c]. Chappuis ("Wied. Ann," xii. 167, 1881) suggests a mixture of Vaseline and white-wax. The writer has used as a cement a stiff pomade consisting of one part of vaseline with three of paraffin wax. This seems to be preferable to organic matters, though probably some mineral cement, such as tungstate of lead or chloride of lead, would be preferable. The fusible material, known to glass-blowers as arsenical glass, or arsenical cement, is preferable in those cases where it can be used."

The beginning of the development of the vacuum-based incandescent lamp in the mid-1800s[10] and the associated need for a self-sustaining good vacuum led to many developments in vacuum technology. One of these was "De Khotinsky cement"—a generic to a group of cements, which contain shellac[d] as their primary binding agent. Achilles De Khotinsky developed this cement while working on the development of incandescent lamps in about 1860. At first this cement was prepared by heating pine tar, adding shellac, and maintaining the temperature of the mixture at 100°C for an hour. Later the cement was improved by changing its composition to 100 parts of flake shellac and 15–30 parts of a plasticizing agent, which instead of pine tar could be creosote[e] or mixtures of similar substances.

Thomas Edison (U.S.) used wax to seal his glass bell jars to the baseplates when sputter depositing gold on his wax "Gold Moulded" cylinder masters (1902 to 1912)[11]. It is interesting to note that as late as 1938 wax sealing was used to seal glass bell jars to base plates. John Strong specifies a mixture of "beeswax and resin" for sealing the bell jar to the baseplate in his 1938 book[12].

In 1928, Cecil Reginald Burch (England) introduced the concept of fractional distillation to segregate the high vapor pressure constituents from oils and greases so that the low vapor pressure constituents would be more vacuum compatible[13]. This led to a series of oils (diffusion pump, mechanical pump) and sealants for vacuum use. One of the first sealants was the Apiezon series of low vapor pressure waxes and greases marketed by Shell-Mex under Burch's Metropolitan-Vickers Electrical Co. Ltd. patents beginning in the early 1930s and continuing until the present time by various distributors.

Epoxy is a term used to denote both the basic components and the cured end products of epoxy resins. Epoxy resins may be reacted (cross-linked) either with themselves through catalytic homopolymerization, (single-component epoxy) or with a wide range of co-reactants referred to as hardeners or curatives (2-part epoxy), and the cross-linking reaction is commonly referred to as curing. Condensation of epoxides and amines was first reported and patented by Paul Schlack (Germany) in 1934 and the discovery of bisphenol-A-based epoxy resins was by Pierre Castan (Switzerland - patented 1938). The trademarked 2-part epoxy "Torr-Seal" is a low-vapor-pressure vacuum compatible epoxy. It was registered in 1961 by Varian Associates (U.S.). Torr-Seal is still sold by various suppliers: other epoxy sealants are available[14].

[b]"India rubber" is from the sap of Para rubber tree *(Hevea brasiliensis)* which is indigenous to South America and which is cultivated in other regions. Charles Marie de La Condamine is credited with introducing samples of rubber to the *Académie Royale des Sciences* of France in 1736. "Congo rubber" is from the sap of vines in the genus *Landolphia,* which are indigenous to Africa. These vines cannot be cultivated, and the intense drive to collect sap from wild plants was responsible for many of the atrocities committed in Africa in the 1800s.

[c]Dr. William Montgomerie, a medical officer in Indian service introduced gutta-percha into practical use in the West in about 1843. Gutta-percha is the sap of trees of the genus *Palaquium,* that are indigenous to the Malaysian archipelago. Gutta-percha is a natural, moldable thermoplastic and found many applications in the mid-to-late 1800s.

[d]Shellac is a resin secreted by the female lac bug, on trees in the forests of India and Thailand. It is processed and sold as dry flakes and dissolved in ethanol to make liquid shellac.

[e]Creosotes are formed by the distillation of various tars, and by pyrolysis of plant-derived material.

TABLE 1. SEALING WAXES AND CEMENTS

Wax	Composition	Softening Temperature; °C	Max. usable Temp.; °C	Vapor pressure Torr, (25°C)	Solvents	Remarks	References [roth] Suppliers (1966)
Soft red wax	Bees-wax (5 pbw) Turpentine (1 pbw) Dyestuff	55 - 60 (wetting)	25	1×10^{-6}	Acetone, alcohol, benzene, turpentine, xylene	Harder than plasticine, loses plasticity by oxidation	Walden[18] Strong[15] Zabel[17]
Faraday wax	Rosin (5 pbw) Beeswax (1 pbw) Venetian red (1 pbw)	60-75 75-95 (wetting)	—	—	Acetone, alcohol, benzene, ether, xylene	—	Walden[18]
Beeswax-rosin	Rosin (1 pbw) Beeswax (1 pbw)	47	40	5×10^{-6}	1:1 mixture of carbon tetrachloride and alcohol	Good adhesion to cold metals	Strong[15] Zabel[17]
Celvacene heavy	—	130	—	1×10^{-6}	Chloroform, acetone	Bonds rubber-to-metal, and bonds rubber-to-glass	CVC
Shellac plus	see text; e.g. shellac (50 pbw), wood creosote (5 pbw), turpentineol (2 pbw), ammonia (1 pbw)	60-80 100-125 (wetting)	—	—	Acetone, alcohol, chloroform, ether, butyl-phtalate	Moderately tough, polymerizes with time	Walden[18]
Red sealing wax	Shellac, Venice turpentine, Vermillion or Chinese red dye	60-80 100-125 (wetting)	—	5×10^{-5}	Acetone, alcohol, chloroform, ether, xylene	Gives under stress	Walden[18]
De Khotinsky cement	Shellac, Caroline (wood) tar	85-100 95-150 (wetting)	40	1×10^{-3}	Acetone, alcohol, chloroform, ether, xylene	Tough, slightly plastic, polymerizes at room temperature over time	CENCO Zabel[17] Walden[18]
Picein (black)	Hydrocarbons from rubber, shellac, bitumen	80 90-105 (wetting)	50	1×10^{-6} 5×10^{-3} (50°C)	Benzene, chloroform, ether, turpentine, xylene	Softens on heating	Strong[15] Edwards Leybold
Wax V	Solid high molecular wt. hydrocarbon, fine inorganic powder, rubber	183 (drops)	30	1×10^{-4}	—	—	Leybold
White sealing wax	Shellac, resins and heat-resistant minerals	106 (drops)	50	1×10^{-3}	Petroleum, benzene, alcohol	Adheres to glass and metal	Leybold
Apiezon Q sealing compound	Graphite, grease or paraffin oil distillates	45 60 (wetting)	30	1×10^{-4} 2×10^{-7} (70°C)	—	Temporary sealing, consistency of plasticine (putty)	Edwards Shell
Apiezon W-40 wax (soft)	Low vapor pressure distillates	45	30	1×10^{-6} 1×10^{-3} (180°C)	xylene	Good flowing characteristics, black wax in sticks	Dow Corning Edwards Shell
Apiezon W-100 wax (medium)	Low vapor pressure distillates	55	55	1×10^{-6}	xylene	Black wax in sticks, Apiezon™ - early 1930s	Edwards Shell
Apiezon W wax (hard)	Low vapor pressure distillates	85 100 (wetting)	80	1×10^{-7} 1×10^{-3} (180°C)	xylene, benzene, chloroform	Higher temperature use, black wax in sticks	Dow Corning Edwards Shell
AgCl	Silver chloride	457 MP	—	1×10^{-7} (300°C)	$Na_2S_2O_3$	Insoluble in H_2O and dilute acids	Roth[19]
TorrSeal™ epoxy	—	—	150	7.5×10^{-7} 5×10^{-6} (100°C)	—	2-part epoxy; cure time 24 hours	Varian Assoc.

Table 1 gives some of the properties of some of the early (some are still available) formulations of vacuum waxes and cements[14–19].

In some cases the electrical properties of vacuum cements are important. To quote[21]: "A good insulating cement for Leyden jars and insulating stands is prepared from sulphur (sic), 100 parts; tallow, 2 parts; and resin, 2 parts; melted together until the consistence of syrup, and sufficient powdered glass added to make a paste."

In 1857, Heinrich Geissler (Germany) invented the platinum-to-glass press seal. This was the only real bakeable vacuum seal until Eldred's multilayer Fe/Ni alloy-core wire seal in 1911[22]. After that there were many graded and direct glass-to-metal seals developed[23,24].

In 1899, Christian Fred Sauereisen (U.S.), who worked with George Westinghouse on the first porcelain electrical insulator, developed a high-temperature, electrically insulating adhesive (cement) that could be used in vacuum. The Sauereisen cement is rather porous but may be made less porous by adding sodium silicate ("water glass") during formulation. The Sauereisen Company is still in business and produces Sauereisen cement (adhesive) No. 31 which can be used to 950°C.

Table 1. Sealing Waxes and Cements. Early Formulations and Their Properties (Adapted from A. Roth, *Vacuum Sealing Technology*, Table 3.1, Pergamon Press, 1966[20] with additions).

Greases

Greases are used between close-fitting moveable surfaces both for sealing and lubrication. Sol Dushman (U.S.) in his 1922 book on vacuum technology gives a formula for making stopcock grease[25]: "A good stopcock grease may be made by heating approximately equal parts of pure rubber and Vaseline. The rubber should be cut into very fine pieces and the heating continued until the mixture is about the consistency of heavy molasses." A later formula used rubber dissolved in Apiezon M grease. Silicone vacuum greases are silicone oils with a thickener such as "fumed" (ultra-fine particle) silica. Table 2 lists some vacuum greases and their properties.

John Strong (1938) recommended "mutton fat" or "Dutch grease" (mutton fat with petroleum oils) for heavy-duty lubrication. A problem with using greases and oils for lubrication in vacuum is that they tend to creep away from where they are needed.

Lubrication in vacuum presents special problems, especially when it involves long-term service such as for space applications. One approach is to use low-shear-strength solid-film lubricants[27,28]. Solid film lubricants include graphite (which is not useable in vacuum since it requires water vapor for its lubricity), sulfides (e.g., MoS_2 - electrical insulator), selenides (e.g., $MoSe_2$ - electrical conductor), and low-shear strength metals such as Ag, Sn, and In. One of the first demanding applications of long-term vacuum lubrication was in rotating anode X-ray tubes (Rotalix X-ray tube by Phillips invented in 1929). A fundamental requirement of the solid-film lubricant is that it adheres to the surfaces being lubricated. In the mid-1960s, the NASA Lewis Research Center (Cleveland) began studying solid film lubricants for space (vacuum) applications using ion plating to deposit adherent films on bearing surfaces[29].

Fluid Seals

Low viscosity fluid seals using mercury were used in the first vacuum seals. When Torricelli made his mercury barometer in 1644 he was essentially using the mercury column as the seal between the atmosphere and the vacuum on top of the mercury column[2]. Many early water pumps were immersed in reservoirs of water so that any leaks were of water. Immersion in fluid (oil or mercury) reservoirs is used in some vacuum seal designs[30]. Low melting point (T_m) metals such as Ga (T_m=30°C), In (T_m=157°C), and Sn (T_m=232°C) and metal

VACUUM GREASES AND THEIR PROPERTIES

Grease	Melting Point (dropping temp.) °C	Max. usable Temp.; °C	Vapor pressure Torr, (25°C)	Remarks	Suppliers (1966)
Vacuum Grease P	55	25	1×10^{-5} 1×10^{-4}(100°C)	1×10^{-8} (degassed)	Leybold
Ramsay grease	56	25-30	1×10^{-7} 10^{-4}@30°C	_	Leybold
Apiezon L	_	30	1×10^{-9} 1×10^{-6}@135°C	_	Edwards, Shell
Apiezon M	_	30	1×10^{-8}	_	Edwards, Shell
Apiezon N	_	30	1×10^{-7}	_	Edwards, Shell
Vacuum Grease R	65	30	5×10^{-6}	VP = 10^{-8} degassed (25°C)	Leybold
Lubriseal	40	30	_	_	CENCO
Vacuseal light	_	50	5×10^{-5}	_	CENCO
Joint grease DD	120	58	_	for rotary seals	Leybold
Vacuseal heavy	_	60	5×10^{-5}	_	CENCO
Celvacene light	90	_	5×10^{-6}	_	CVC
Celloseal	100	_	5×10^{-6}	_	Fischer
Apiezon T	_	110	5×10^{-8}	_	Edwards, Shell
Celvacene medium	120	_	$<5 \times 10^{-5}$	_	CVC
Cello grease	120	150	$<5 \times 10^{-5}$	_	Fischer
Lithelen	_	_	very low	Lithium soap	Leybold
Silicone Stockcock grease	_	200	5×10^{-7} 10^{-5}@170°C	rotary seals	Dow Chemical Co. Edwards
Silicone high vacuum grease	250	200	5×10^{-7} 1×10^{-5}@170°C	useful to -40°C	Dow Chemical Co. Edwards

Table 2. Vacuum Greases and Their Properties (Adapted from A. Roth, *Vacuum Sealing Technology,* Table 3.10, Pergamon Press, 1966[26]).

alloys[f] may be used as liquid sealants if the joint is kept above the melting point of the metal (if cooled it becomes a soldered joint).

Mercury was used as internal seals in some valve designs. One such mercury-sealed stopcock was described by Thompson in 1887 (Eiloart's design) (Fig. 40, p. 29[8]). It used mercury-filled circular grooves in the stem portion of a taper-plug with a straight-through stopcock above and below the passage. Shenstone described other valve and trap designs related to mercurial pumps in his 1886 book on glass blowing[31], as does Roth in his 1966 book on vacuum sealing[30].

The movement of a fluid may be used as a "cut-off" seal to separate gases in portions of a vacuum system[32]. An early example is the use of mercury in the McLeod gauge (1873) to isolate a volume of gas that is then compressed.

Most recently low-vapor-pressure oils with suspended magnetic particles ("ferrofluids")[33] have been used for vacuum seals. The magnetic particles allow the oils to be kept in place using a magnetic field. The "ferrofluids" were invented by Stephen Papell (NASA) in 1963[34]. Vacuum components using ferrofluid seals are made by several companies[35,36].

[f] An interesting low-vapor-pressure liquid metal alloy is Galinstan, which is a Ga:In:Sn (~68:22:10) alloy that melts at -19°C. Sometimes bismuth is added to increase fluidity.

Paints

The development of metal vacuum chambers in the 1920s revealed several materials problems. Namely the cold rolled steel of that time was porous and not a good vacuum material and the welding process used to join metals gave porous welds that were not vacuum tight[g]. The solution was to paint the outside of the vacuum chamber[37]. For example, see Fig. 2 (top) in reference[38].

Glyptal (trademarked by GE in 1926)[37,39] is a paint used to seal pores in cold rolled steel and welds (as well as castings) and was the preferred paint for vacuum chambers for many years. Glyptal Resin 7 is formed by the interaction of glycerine and phthalic anhydride. Glyptal along with sprayable (single-component) epoxy paints are sometimes still used to seal pores in vacuum systems and components.

Rubber

Natural rubber ("India rubber" or "caoutchouc") is from the sap of the rubber tree and was used for many years as a coating to waterproof cloth (Macintosh cloth) but had a problem that it became "tacky" if it got warm. This stability problem was solved by Charles Goodyear (U.S.) with his discovery of the vulcanization process using sulfur (1839)[40]. Both Goodyear (U.S.) and Thomas Hancock (England) patented the vulcanization process in 1844.

In the era of Geissler, Topler, Sprengel, and Geissler/Spengel mercury pumps (mid-to-late 1800s), rubber tubing was used to allow the mercury reservoir to be raised and lowered. The vulcanized rubber contained excess sulfur, which reacted with the mercury and formed a film on the glass. This contamination had to be periodically removed. The rubber tubing was typically pre-cleaned by boiling for a number of hours in a 10% caustic solution to remove excess sulfur and degas the rubber[41].

The first patent for an elastomer O-ring seal (O is the shape in cross-section) for use in high-pressure hydraulic applications was a Swedish patent by J.O. Lundberg, issued on May 12, 1896. The elastomer O-ring/groove system of sealing

[g] The Vacuum Induction Melting (VIM) process eliminates most of the porosity problem in steel and is generally specified for vacuum chamber steel. E.F. Northrup built the first prototype of a vacuum induction furnace in 1920 in the U.S. (Alfred Mühlbauer, *History of Induction Heating and Melting,* Vulkan-Verlag (2008) ISBN 978-3-8027-2946-1). TIG (Heliarc) welding provided a great advance in vacuum chamber manufacturing by allowing pore-free internal welds to be made easily. Russell Meredith of Northrop Aircraft perfected the TIG process in 1941. Meredith named the process Heliarc because it used a tungsten electrode arc and helium as a shielding gas, but it is often referred to as tungsten inert gas welding (TIG). The American Welding Society's official term is gas tungsten arc welding (GTAW).

was patented in the U.S. in 1937 for sealing piston/cylinder systems for hydraulic/pneumatic equipment by Neils Christensen[42]. The elastomer O-ring/groove design is now commonly used for large-area vacuum seals[43].

John Strong describes use of flat rubber gaskets (cut from sheet—not O-ring) in his 1938 book[44] and advises that if the rubber is exposed to the vacuum then "it is advisable to boil it in a 15 percent caustic solution (potassium hydroxide or sodium hydroxide) to dissolve free sulfur and remove talc from the surface." If rubber becomes cracked with age, Strong recommends coating it with castor oil. Apparently he had no experience with the new artificial rubbers.

There were a number of attempts to produce artificial rubber in the early 1900s. The most successful were "Neoprene" rubber introduced in 1933 by E.I. DuPont (U.S.) and "buna-N" (nitrile) and buna-S rubber introduced in 1935 from Germany[45,46]. Molded sealing gaskets of this material began to be used by the vacuum industry by the late 1930s. For example molded "L" shaped rubber gaskets replaced wax for sealing glass and metal bell jars to baseplates[47].

In 1957, Viton A (E.I. DuPont) fluoroelastomer polymer was introduced to the aerospace industry and is the preferred elastomer for high temperature (up to 200°C). Viton has a lower gas permeation rate than either the neoprene or the buna rubbers. Kelrez (E.I. DuPont) is a similar product with a slightly higher operational temperature (up to 250°C).

The "spacer seal" is a flat-surface sealing system that uses an O-ring held between a centering/spacing ring that retains the O-ring and determines the compression of the "O-ring" (Leybold and Heraeus catalogs ~ 1960)[48]. The diameter of the O-ring is greater than the retaining plates therefore when the surfaces are mated metal-to-metal the compression of the O-ring provides the vacuum seal. The O-ring system is compressed between two smooth surfaces (i.e., it is a "sexless" seal). The name KF (Klein Flansche—small flanges) seal was adopted by ISO and DIN standards organizations. There is always a debate between vacuum technologists as to whether elastomer O-rings should be lightly greased or not.

Metal Deformation Seals

The development of metal vacuum chambers in the 1920s[23,38] led to the development of new sealing materials[49] and seal designs. The metal flanges allowed the use of bolts and clamps to apply pressure to deform gaskets.

One of the first large metal chambers for vacuum coating was built by John Strong to coat the 36-in. Lick Observatory astronomical mirror in 1930 {Fig. 2a[38]}. The greater than 36-in. diameter deformable wire metal gasket was retained in a groove and was made of fuse (lead) wire. The details of the metal seal are shown in Strong's book *Procedures in Experimental Physics."*[12]

Subsequently there were a number of papers and patents on metal gasket seals[50-52] using various metals (Al, Au, Ag, In, OFHC copper, etc.) and various surface configurations on both the flange surface (stepped seals, knife-edge seals) and on the metal gasket (coined gaskets)[53].

In the 1950s, vacuum systems started to become more complex, especially for surface science research where there could be more than 30 vacuum seals and the seals needed to be reliable and bakeable to ~ 400°C in order to achieve a very high vacuum[49,54]. In 1961, Maurice Carlson and William Wheeler of Varian Associates (U.S.) patented what became the ConFlat sealing system using knife-edges machined on recessed surfaces that dug into a copper gasket as the surfaces were pressed together[55]. The seal design is a knife-edge that is machined in a groove below each of the flange's flat surfaces. As the bolts of a flange-pair are tightened, the knife-edges make an annular indentation on each side of a single-use soft copper gasket that fits in the groove. The extruded metal fills all the machining marks and surface defects on the knife-edge surfaces, yielding a leak-tight, bakeable seal. The ConFlat system later became designated the CF flange by ISO, DIN, and other standards organizations.

The ConFlat flange has the disadvantage that it can't easily be scaled up to large diameters so William Wheeler of Varian designed and patented a wire gasket "corner seal" that could be scaled up to at least a 10 ft in diameter ("Wheeler seal") (1965)[54,56] which is very similar to the seal that Strong described in 1938[12].

Summary

The vacuum sealing materials used through the early 1900s were made from naturally occurring substances such as insect products (beeswax and shellac), petroleum derivatives (petroleum jelly {1859 - Vaseline™}, paraffin wax, and creosote), and plant derivatives (pine rosin, natural rubber, gutta-percha, and creosote). In the 1930s, more tailored sealing materials and seal designs for vacuum use began to emerge.

The desirability of materials to be used as sealants or greases for vacuum applications depends on their vapor pressure, outgassing properties, stability under use conditions, as well as their ability to prevent ingress (permeation, leaking) of gases and/or vapors from the ambient into the vacuum space. The vapor pressure of a material is the equilibrium pressure of the constituents of a material in contact with the material and is a measure of the evaporation rate when the material is in a vacuum. Outgassing may be from dissolved gases/vapors or may be from decomposition products of the material. These properties may depend on the history of the material such as how long it has been under vacuum and at what temperature ("degassing"). The properties of some materials may change with time. Thus data for a property such as outgassing rate (Torr-liter/cm^2/sec) should include a statement about the history of the material, e.g., Torr-liters/cm^2/sec (after 100 hours at 100°C under vacuum).

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