Vacuum switches

for negative pressure from 950 mbar to 100 mbar



- Switching point can be adjusted when fitted on site[1)]
- High overpressure resistance
- Long service life even under harsh conditions
- 0150 series available as changeover contacts up to 250 V
- 0151 series available as NC or NO up to 42 V

[1)] Pressure switches can also be supplied preset at factory.
Our preset switches are sealed with lacquer paint, set points are embossed on the housing.

Vacuum switches

Technical details

Type:	0150	0151
Operating voltage:	10 … 250 VAC/DC	10 … 42 VAC/DC
Rated current (resistive load):	Refer to electrical values below	10 mA … 4 A
Switching power:	Refer to electrical values below	100 VA
Temperature resistance of sealing materials:	-20 °C … +100 °C	-15 °C … +120 °C
Switching frequency:	200 / min	
Mechanical life expectancy:	1,000,000 cycles	
Pressure rise rate:	≤ 1,000 bar / s	
Vibration resistance:	10 g; 5 … 200 Hz sine wave; DIN EN 60068-2-6	
Shock resistance:	294 m/s^2; 14 ms half sine wave; DIN EN 60068-2-27	
Housing material:	Aluminium	Brass
Protection class:	IP65 with socket device	IP65, terminals IP00
Weight:	approx. 270 g	approx. 140 g

0150 Electrical values (also refer to page 14 for technical explanations)

Rated working voltage U_e	Rated working current I_e (usage category)
250 VAC 50 / 60 Hz	5 A (AC 12)
250 VAC 50 / 60 Hz	1 A (AC 14)
24 VDC	3,5 / 3,5 A (DC 12 / DC 13)
50 VDC	2 / 1 A (DC 12 / DC 13)
75 VDC	1 / 0,5 A (DC 12 / DC 13)
125 VDC	0,3 / 0,2 A (DC 12 / DC 13)
250 VDC	0,25 / 0,2 A (DC 12 / DC 13)
Rated insulation voltage U_i:	300 V
Rated impulse withstand voltage U_{imp}:	2,5 kV
Conventional thermal current I_{the}:	6 A
Switching overvoltage:	< 2,5 kV
Rated frequency:	DC and 50 / 60 Hz
Nominal current of short-circuit mechanism:	up to 6,3 A
Conditional short-circuit current:	< 350 A
Tightening torque of terminal screws:	< 0,35 Nm
Connector cross-section:	0.5 … 1.5 mm^2

0151

Vacuum switch up to 42 V, NO or NC

- Brass housing
- Spade or M3 screw terminal
- Operating voltage up to 42 V
- Overpressure safety up to 35 bar[1)]

p_{max} in bar	Adjustment range in mbar (relative)	Tolerance at room temperature in mbar	Thread	Article number
0151 Vacuum switches with M3 screw terminal				NO —› |:
35[1)]	200 – 950	± 100	G 1/8 female	0151 - 452 15 - 3 - 001
				NC —› :|
				0151 - 453 15 - 3 - 001
0151 Vacuum switches with spade terminal				NO —› |:
35[1)]	200 – 950	± 100	G 1/8 female	0151 - 454 15 - 3 - 001
				NC —› :|
				0151 - 455 15 - 3 - 001



Seal material – Application areas

FKM	Air, oils, greases, fuel/gasoline	3

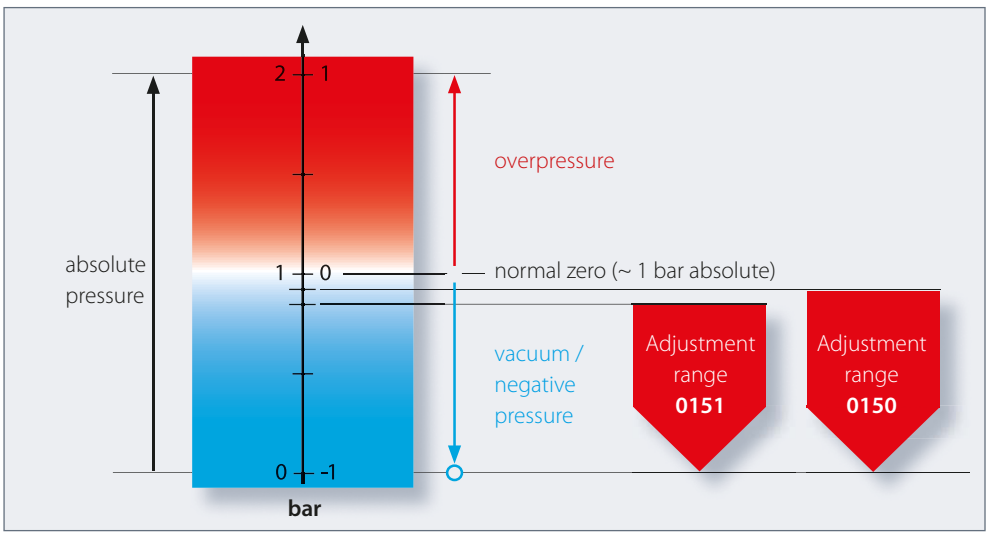
Temperature resistance: -15 °C … +120 °C

Article number:	0151 – 45X 15 – 3 – 001



Switches are also available on request with outer thread or integrated connector.

Comparison of absolute/relative pressures



Note: Required set points in the vacuum range must be specified relative to atmospheric pressure (normal pressure) in the ordering process.

[1)] Static value. Dynamic value is 30-50 % lower. Values pertain to the hydraulic/pneumatic part of the pressure switch.

General technical explanations

User information
Our pressure monitoring products may only be installed and started up by authorised specialists. The safety regulations of country-specific authorities must be observed, especially when working with mains voltages and oxygen, and in potentially explosive areas.

Product information
The technical information in this catalogue is based upon fundamental testing during product development and empirical values. The information cannot be used for all application scenarios.

Testing of the suitability of our products for a specific application (such as the checking of material compatibilities) remains the responsibility of the user. It may be the case that suitability can only be verified by appropriate field testing.

Mounting position
For mechanical and electronic pressure switches as well as transmitters there is no limitation due to the mounting position with regard to the accuracy of the pressure measurement.

However, other boundary conditions of the application may require a certain mounting position, e. g. horizontal installation to avoid waterlogging on the electrical connection or vertical installation to prevent debris from accumulating in the bore of the pressure connection.

IP protection class
The IP protection class is a defined protection level code (sealing) of electrical equipment housings in line with IEC 60529 (formerly DIN 40050 – Part 2). Protection of a housing against the following is tested here:

- The penetration of solid extraneous particles, such as dust
- Access of hazardous parts
- Penetration of water

IP protection tests are performed as type tests.

The IP protection type code, made up of two digits, specifies the protection of a housing against the penetration of solid extraneous particles and water.
The numeric code therefore provides conclusions to be drawn on the level of personal safety as well as the functional protection / mid to longterm functional reliability of electrical equipment.

Protection types IP00, IP65, IP67 and IP6K9K

IP00:
No protection against penetration of solid particles or water, no protection against contact.
IP6X:
Protection against penetration of dust (dust proof). Full contact protection.
IPX5:
A jet of water from a nozzle, aimed at equipment (such as a pressure switch) from all directions, must not have any harmful effect.
IPX7:
Protection from water, when equipment (such as a pressure switch) is immersed in water under defined pressure and time conditions. Water must not penetrate into the equipment in harmful quantities.
IP6K9K:
Devices satisfying these requirements must be dust-proof and be able to withstand loads during the use of high-pressure cleaners and steam jets. The standard stipulates a water pressure from 80 to 100 bar at a temperature of 80 °C for testing.
IP6KX:
Dust must not penetrate. Letter K: Specific to the electrical equipment of road vehicles.
IPX9K:
Protection against penetration of water at high pressure / for steam jet cleaning. Water aimed at the housing from every direction at greatly increased pressure may not have any damaging effects.

We are able to offer IP67 / IP6K9K for many of our mechanical and electronic pressure switches (pre-wired or with integrated connector) and for our transmitters.

IP67 / IP6K9K is the recommended protection for mobile hydraulics and any equipment exposed to the outdoor environment.

Cylindrical threads
Cylindrical threads are either sealed on the front by underlaying an appropriate sealing ring (such as a copper sealing ring) or by already having integrated O-rings or gakets.

If the corresponding thread types do not provide specifications regarding the roughness of the counter sealing surface, we recommend the following values:

R_{amax} 1.6 | R_{max} 6.3 | R_{mr}(-0.10) > 5 % C_{ref} 5 %

Conical threads
(cone-shaped threads)
Conical threads guarantee tolerance compensation of the two threaded parts. The sealing function is realised with thread flanks which deform permanently and enter into a metallic frictional fit. Conical threads are not screwed in down to the screw-in depth, but fixed with the tightening torque required for the leak tightness.

Remember not to exceed the permitted tightening torque of the pressure switch or transmitter presented in the following table (to prevent damaging the threaded pin beforehand, causing it to become untight during operation or to snap off when tightened).

Tightening torques of steel threads
The specifications below are to be understood upper material thresholds for the housing of pressure switches or transmitters. Remember during installation that the type and material of the seal, the condition of mating surfaces (e.g. dry or oily) and the material of the counter-piece all have a bearing on the tightening torque.

Threads M10, G 1/8, R 1/8 and NPT 1/8 are limited to overpressure strengths of up to 600 bar.

Values 30% lower than in the following table must be used for brass housings.

Thread	Tightening torgue
NPT 1/8; M 10 x 1 conical	max. 18 Nm
M 10 x 1 cyl.; G 1/8	max. 20 Nm
M 12 x 1.5; 7/16 – 20 UNF	max. 30 Nm
G 1/4; 9/16 – 18 UNF	max. 40 Nm
NPT 1/4; M 14 x 1.5	max. 40 Nm

Gaseous applications
In particular using additional sealant to attain the required leak tightness may be necessary for gas applications.

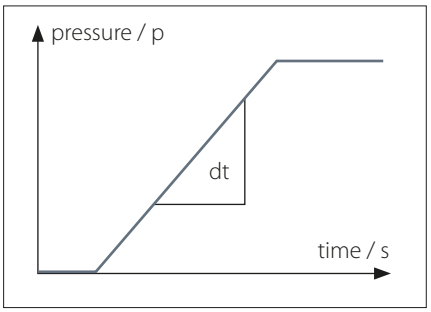
Plasma cleaning for oxygen applications
When pressure switches/transmitters are used with oxygen, the surfaces must be free of oil and grease residues to prevent spontaneous combustion. Special requirements must also be observed for oxygen applications with regard to the material selection of housings and seals as well as the permitted operating pressure (see also page 17). We would be pleased to advise you if necessary.

For these operating conditions, we offer plasma cleaning of the components in order to achieve the required elimination of oil and grease. The components are packed and sealed in plastic bags. The packaging is marked with safety instructions for use in oxygen applications.

Plasma cleaning LABS-free (PWIS-free)
Our products are always manufactured without the use of substances that interfere with the wetting of the paint throughout the entire manufacturing process. For use in LABS-free applications, we offer plasma cleaning of the components. The components are packed and sealed in plastic bags. The packaging is marked with safety instructions for use in LABS applications.

Vacuum
The values given in the technical details for the vacuum range are specified in millibars (mbar) below atmospheric pressure.

Pressure change rate (~rise / ~fall)
The pressure change rate denotes the pressure over time for the rising/falling pressure. It is specified in bar/s.



The maximum pressure change rate for mechanical pressure switches is 1,000 bar/s. For SUCO electronic pressure monitoring products the maximum pressure change rate can be up to 5,000 bar/s.

Overpressure protection
The specified overpressure protection in the catalogue is based on a static pressure. The values refer to the hydraulic or pneumatic part of the switch.

It is best practice to use 30 - 50% lower values for dynamic pressure compared to static pressure. These empirical values are based on the knowledge that, in pressure systems, unexpected pressure peaks which are higher than the working pressure are generated as a result of activation of valves, sudden falling or rising load or simply the change of cross-sections in the pipes. With conventional measurement techniques (such as manometers), these pressure peaks are hardly measureable. Faster measurement systems must therefore be used for this data acquisition. Attempts are being made to take this into account by using emperical or corrective factors.

If the pressure conditions are known and the pressure change rates are 100 bar/s, our pressure switches and transmitters can be used up to the permitted overpressure protection as per data sheet / catalogue. Only 50 % of the specified overpressure protection is permitted when operating at the maximum permitted pressure change rate of ≤ 1,000 bar/s for mechanical pressure switches, and at ≤ 5,000 bar/s for transmitters.

RoHS-Compliance
= **R**estriction **o**f **H**azardous **S**ubstances (Directives 2011/65/EU and 2020/863/EU)

CE-Mark
= **C**ommunauté **E**uropéenne

European Parliament and Council directives must be observed when products are launched onto the market. If a directive existsfor a product, it must be applied. Only products for which a directive exists may bear the CE mark.

Only products which have been tested according to CE directive or corresponding standards may carry the CE mark.

Mechanical pressure switches with a supply voltage above 50 VAC or 75 VDC are covered by the 2014/35/EU Low Voltage Directive. Variants for potentially explosive areas are covered in addition by the 2014/34/EU ATEX Product Directive.

Our electronic products satisfy EMC (Electromagnetic Compatibility) Directive 2014/30/EC. Mechanical pressure switches do not fall under the EMC Directive.

The Machinery Directive 2006/42/EC is not applicable, because our products are classed as components.

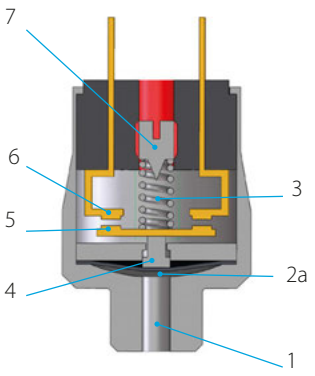
Our product designs are based upon „good engineering practise" in line with Article 4, Paragraph 3 of the Pressure Equipment Directive (2014/68/EU), meaning neither a declaration of conformity may be issued nor a CE mark affixed.

The current product-specific EU declaration is available in the download area of our homepage:
www.suco.de/en/downloads

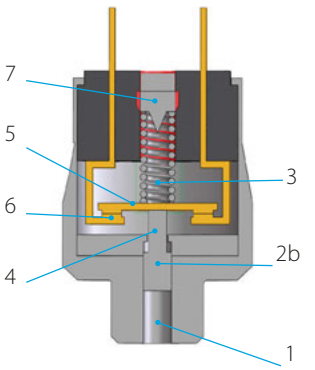
Subject to technical changes

Technical explanations for mechanical pressure switches

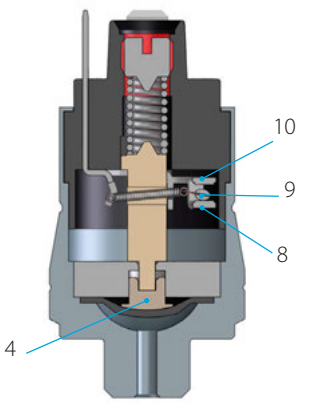
Diaphragm pressure switch
NO



Piston pressure switch
NC



Change-over



What is a mechanical pressure switch?
Mechanical pressure switches from SUCO monitor the pressure of liquid or gaseous media, and close or open an electrical circuit on reaching a set threshold.

Diaphragm pressure switches
SUCO diaphragm pressure switches are used in pressure ranges from 0.1 bar to 100 bar, meaning overpressure safety of 35, 100, 300 / 400 and 600 / 700 bar, depending on the used diaphragm type.

Piston pressure switches
Pressure ranges from 10 bar to 400 bar can be monitored with SUCO piston pressure switches (dependent on size); overpressure safety of up to 600 / 700 bar can be attained.

Sizes of pressure switches
Mechanical pressure switches from SUCO can be divided into sizes hex 24, hex 27 and 30 A/F. Each particular size has specific hydraulic, pneumatic and electric properties (specified on the relevant catalogue page in the technical details).

How does a pressure switch work?
Function description for **normally open (NO):** Pressure is applied to the diaphragm (2a) / pistons (2b) through the pressure connector (1).
If the generated pressure force is greater than the force of the pre-tensioned pressure spring (3), the plunger (4) moves towards the counter-contact (6), carrying along the contact disc (5), and closes the circuit.
The switch opens again when the pressure is reduced by the hysteresis value.

Function description for **normally closed (NC):** Engaging happens in the reverse order.

The adjustment screw (7) enables the switching point to be changed within the adjustment range.
The micro switch of a **change-over contact system** (snap-action) offers both, a NC and a NO contact.
The swivel contact (9) is activated by the plunger (4). The circuit is closed by the NC (8) as long as no pressure is applied.
When the applied pressure exceeds the set switching point, the swivel contact changes over and closes the circuit via the NO (10).

Utilisation category
The utilisation category specifies for example voltages and currents, and the type of load, our pressure switches are designed for (according to DIN EN 60947-5-1).

AC voltage
AC12: Control of ohmic loads and semiconductor loads in input circuits of optocouplers (such as PLC inputs).
AC14: Control of electromagnetic loads, 72 VA.

DC voltage
DC12: Control of ohmic loads and semiconductor loads in input circuits of optocouplers (such as PLC inputs).
DC13: Control of electromagnets.

B10d value
According to DIN EN ISO 13849-1, the B10d value specifies the anticipated service life (with a 10% probability of failure). The B10d value is therefore directly dependent on the respective application of the pressure switch. For ohmic loads and currents < 1 A, we specify the B10d value as 1 million cycles of electrical life.

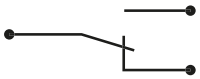
The specification of a MTTF time (mean time to failure) is not possible without knowing the specific conditions in the application. However, the MTTF time can be determined easily from the B10d value:

$$MTTF_d = \frac{B_{10d}}{0{,}1\, n_{op}}$$

n_{op}: number of cycles per year
B_{10d}: number of cycles until 10 % of components have failed.

Minimum current / minimum working voltage
The minimum working current and minimum working voltage depend greatly on operating and ambient conditions. Physically, the build-up of impurity layers on the contact rivets must be countered with mechanical friction and/or electrical erosion.

Classification of electrical switch functions

			Contact form DIN EN-60947-5-1	Symbol IEC 60617
NO	NO, normally open	SPST single pole, single throw	X	
NC	NC, normally closed	SPST single pole, single throw	Y	
Change-over contacts	CO, change over (snap action)	SPDT single pole, double throw	C	

It has proven useful in many applications to deploy our pressure switches with silver contact rivets ensuring that they are fail safe to 10 mA and 10 V. Variants with gold contacts are available in our catalogue for even lower currents and voltages.

Potential-free – galvanically isolated
Mechanical pressure switches from SUCO are potential-free, i.e. no auxiliary energy is required. Also, there is no electrical contact between the individual, live parts and the housing.

Adjustment range of switching point
The pressure range, within which the switching point of a pressure switch can be set, is called adjustment range. The switching point corresponds to the pressure value at which the electric circuit is opened or closed by the pressure applied.

If no switching point is specified on order, the pressure switches are adjusted by approximately half the adjustment range at factory.

The setting ranges specified for the respective device series apply to increasing pressure.
For switching points that are specified for falling pressure and are within the maximum value of the setting range minus the hysteresis, the next higher setting range must be selected (see also section „Hysteresis").

Switching point tolerances
The switching point tolerances specified by us pertain to room temperature (RT) and condition as new.

The values can change as a result of temperature, ageing and deployment conditions.

It is not possible to specify generally applicable value for switching point tolerances over temperature as the medium has a significant influence on the sealing materials in the pressure switch.

Double the tolerance stated for RT and condition as new can be assumed as a typical magnitude for the tolerance over the entire temperature range.

Based on their design, piston switches may exhibit an increase in switching points due to storage (dry run, stick-slip effect). Following a short start phase, the switching points return to the value set at the factory.

Pressure change rates of > 1bar/s may have an effect on the switching point for diaphragm pressure switches.

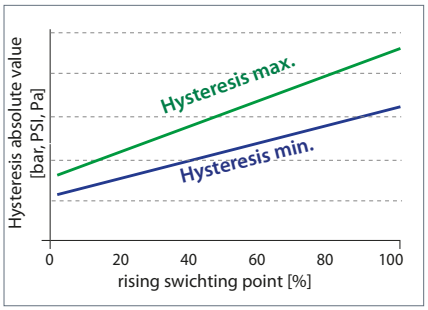
The switching point (for rising pressure) and hysteresis increase, whilst the switch-back point (for falling pressure) sinks.

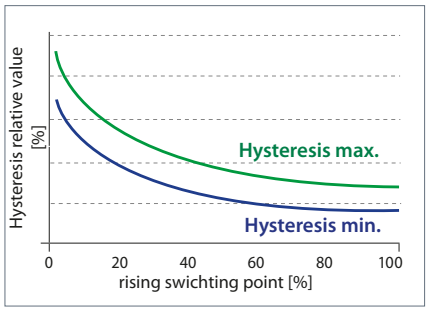
Also, the effect of the maximum (system) pressure on the switchback point (for falling pressure ramp) must be factored in for tolerance-critical applications. The higher the (system) pressure, the lower the resulting switch-back value.

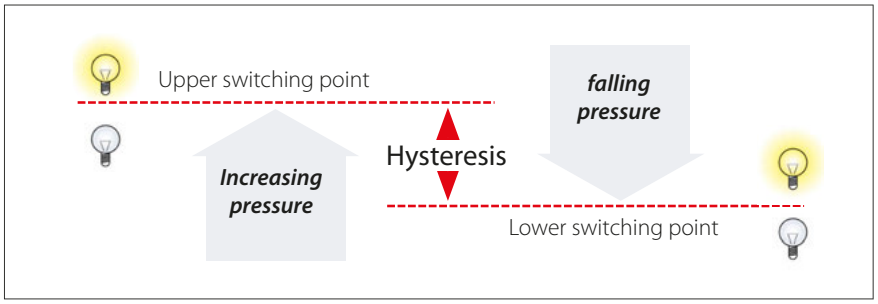
Hysteresis
Rising / falling switching point
The pressure difference between the rising (upper) and falling (lower) switching points (refer to the figure, e.g. NO) is known as hysteresis (switch-back difference).

Hysteresis has no constant value due to the structural layout of a mechanical pressure switch. In absolute values, the hysteresis is also the smallest with the smallest adjustment range. The hysteresis increases with increasing adjustment range.

Hysteresis over rising switching point







Technical explanations for mechanical pressure switches

Hysteresis can be set at SUCO in range from approx. 10 % (at end of adjustment range) to 30 % or higher (at start of adjustment range), related to the respective switching point for hex 27 and 30 A/F pressure switches with adjustable hysteresis.

Due to their design, pressure switches with an overpressure resistance of 100 bar have smaller hystereses than the series with 300 bar or 400 bar overpressure resistance. Piston pressure switches have a slightly larger hysteresis than diaphragm pressure switches.

The specifications in the catalogue only represent typical average values. Please ask about the possible setting ranges you may require. Our electronic pressure switches are excellently suited to extremely low or high hysteresis. The lowest possible hysteresis is set if nothing is specified in the order.

Switching frequency
The switching frequency provides information on the possible number of cycles in one minute. The value of 200/min specified by us is a guideline value. Higher switching frequencies can be attained depending on switch type and conditions of use.

Sealing materials
The priority in sealing material selection is the chemical resistance. The temperature range only becomes a selection criterion when different sealing materials are suitable for the medium.

NBR (Buna-N)
This is the standard material most commonly used. It is a special SUCO material mix with high level of cold flexibility so that the sealing properties of the pressure switch are also retained at low temperatures.

NBR is denoted by number „1“ in our order number.

EPDM
This material is the solution of choice for applications with brake fluids. It is particularly suitable for applications with (process) water. Approval from the BAM (Federal Institute for Material Testing) is in place for oxygen applications.

The safety regulations from country-specific authorities must be observed for oxygen applications. EPDM may not come into contact with oil because this would entail swelling and softening of the material, and so failure of the pressure switch.
EPDM is denoted by number „2“ in our order number.

EPDM-TW with drinking water approval
This EPDM material is intended for drinking water applications (up to max. 35 bar overpressure safety) according to Elastomer Guideline, WRAS (Water Regulation Advisory Scheme), ACS (Attestation de Conformité Sanitaire) and NSF 61 (National Sanitation Foundation) and for use in medical and pharmaceutical applications.

EPDM-TW may not come into contact with oil because this would entail swelling and softening of the material, and so failure of the pressure switch. Sealing is only available upon request, so please consult us before ordering.
EPDM-TW is denoted by number „5“ in our order number.

FKM / FPM (Viton®)
This is a diaphragm material suitable for high temperature exposure and exhibits special chemical resistance. It has been tested in the hydraulic sector and has been proven to work successfully with critical oils.
FKM / FPM is denoted by number „3“ in our order number.

FFKM
This diaphragm material is suitable for temperature exposure up to 120°C and can withstand very aggressive conditions such as chemical species including organic or inorganic acids, diluted alkalis, ketones, esters, alcohols, fuels and hot water.
FFKM is denoted by number „6“ in our order number.

TPE (Thermoplastic elastomers)
This sealing material is available only for our electronical products of the Performance Series.
TPE offers similar media compatibility like NBR, e.g suitable for mineral oil and hydraulic fluids.
Additionally the material can be used with diluted acids and bases and cold water, too.
TPE is denoted by number „7“ in our order number.

ECO (epichlorhydrin)
ECO is only used in our vacuum switches. This material has similar properties to NBR in terms of chemical resistance, and can be used in gas applications as well as oil and fuel applications.

ECO is denoted by number „4“ in our order number.

Silicone
Silicone is suitable for use within a wide temperature range. The SUCO silicone diaphragm is FDA-approved (Food & Drug Administration) for the food sector.

Silicone is a soft material reserved for sensitive applications in the low pressure range (below 10 bar) with maximum overpressure safety to 35 bar. Piston switches are therefore not offered with silicone seals. Silicone is also not suitable for oil applications.
Silicone is denoted by number „8“ in our order number.

H-NBR
This is a special SUCO material mixture optimised for ester-based bio-oils. The multitude of bio-oils on the market means suitability of the material for the respective oil must be determined. This diaphragm material can also be used for a number of mineral and synthetic oils.

H-NBR is denoted by number „9“ in our order number.

Medium compatibility
The specifications on medium compatibility in this catalogue cannot be generalised as they pertain to the sealing materials used in our pressure switches.

Saturated and superheated steam applications
The sealing materials mentioned are not suitable for saturated or superheated steam applications.

Conversion table for pressure units

Unit symbol	Unit name	Pa= N/m²	bar	Torr	lbf/in², PSI
1 Pa = N/m²	Pascal	1	0.00001	0.0075	0.00014
1 bar	Bar	100 000	1	750.062	14.5
1 Torr = 1 mmHg	Millimetres, mercury column	133.322	0.00133	1	0.01934
1 lbf/in² = 1 PSI	Pound-force per square inch	6 894	0.06894	51.71	1

Conversion table for temperature units

	K	°C	F
K	1	K - 273.15	9/5 K - 459.67
°C	°C + 273.15	1	9/5 °C + 32
F	5/9 (F + 459.67)	5/9 (F - 32)	1

Water applications
Standard piston switches are not suitable for water applications.
Pressure switches in stainless steel with EPDM seal have a special sealing system and can therefore also be used for water with corrosion protection, water mixtures or emulsions. The use of other fluid mixtures should be clarified with SUCO (e.g. swelling of EPDM sealing could happen by water – oil mixture).

Pressure switches with stainless steel housings with EPDM-TW diaphragm, SUCO type „5" are designed for the use of drinking water.

Gas applications
Our pressure switches are suitable for liquid and gaseous media. Gaseous media place particular demands on leak-tightness how ever. The leakage rate is dependent on the respective gaseous medium, the working pressure and the permeability of the seal material used in the pressure switch.
Their lower leakage rates mean diaphragm pressure switches are better suited for gas pressures than piston pressure switches. The latter can also be used however if certain measures are taken (such as venting of the housing).

For gaseous applications below 10 bar (145 PSI) in combination with pressure switches with high IP class, i.e. IP 67 and IP6K9K, in general we recommend to use ventilation. Please consult us; we are able to offer suitable solutions.

Oxygen applications
Our mechanical pressure switches are suitable for use with oxygen. We recommend the use of our EPDM diaphragm. The resistance to internal burnout of the diaphragm has been tested by the BAM (Federal Institute for Material Testing).

Pressure switches with steel housings with zinc-nickel coating are, in conjunction with oxygen, only approved to a maximum working pressure of 10 bar.

Pressure switches with brass housings are, in conjunction with oxygen, only approved to a maximum working pressure of 35 bar.

Pressure switches with stainless steel housings are, in conjunction with oxygen, only approved to a maximum working pressure of 50 bar.

Please consult us about gas, water and oxygen applications.

Subject to technical changes.

DGUV accident prevention regulations (such as DGUV 500, Section 2.32 and BGI 617) must be observed for first operation.

Please specify when ordering „oil and grease-free, for use with oxygen".

Underpressure safety of pressure switches
Our pressure switches are underpressure safe down to 300 mbar (relative).

Overpressure safety of vacuum switches
Our vacuum switches are overpressure safe up to 20 or 35 bar depending on type.

cCSAus approval
Almost all of our mechanical pressure switches (sizes hex 24 and hex 27), and vacuum switch 0151, have cCSAus approval. The CSA mark together with „c" and „us" combines the control stamps for introduction onto the Canadian and American markets. The cCSAus certificate also includes the test of the relevant UL standard.

Checked by an official institution and verified with regular company visits by CSA inspectors, this approval guarantees the highest levels of quality and operational reliability for our products.

You can download the current cCSAus certificate on the download area of our homepage: *https://www.suco.de/en/downloads*

Product information
The technical information in this catalogue is based upon fundamental testing during product development, as well as upon empirical values. The information cannot be used for all application scenarios.

Testing of the suitability of our products for a specific application (e.g. also the checking of material compatibilities) rests under the responsibility of the user. It may be the case that suitability can only be guaranteed with appropriate field testing.