FIGARO

an ISO9001 company

Technical Information for Maxell Oxygen Sensor SK-25

The Maxell Oxygen Sensor SK-25 is a unique galvanic cell type oxygen sensor which provides a linear output voltage signal relative to percent oxygen present in a particular atmosphere. The sensor features no position dependency, excellent chemical durability, and it is not influenced by CO_2, making it ideal for oxygen monitoring.

1. Introduction

The Maxell Oxygen Sensor SK-25 is a unique galvanic cell type oxygen sensor manufactured by Maxell, Ltd. in Japan. Its most notable features are an excellent chemical durability, no position dependency, and it is not influenced by CO2.

2. Basic Information and Specifications

2-1 *Features*

* Virtually no influence from CO_2, CO, H2S, NO, H_2
* Temperature compensation circuit included
* Good linearity
* No position dependency
* Stable output signal
* No external power supply required for sensor operation
* No warmup time is required

2-2 *Applications*

* Safety - Oxygen monitors
* Environmental controls - Combustion gas monitoring
* Food industry - Refrigeration, greenhouses
* Education – Science lab instruments

2-3 *Structure and operating principle*

The SK-25 is a lead-oxygen battery which incorporates a lead anode, an oxygen cathode made of gold, and a weak acid electrolyte. Oxygen molecules enter the electrochemical cell through a non-porous fluorine resin membrane and are reduced at the gold electrode with the acid electrolyte. The current which flows between the electrodes is proportional to the oxygen concentration in the gas mixture being measured. The terminal voltages across the thermistor (for temperature compensation) and resistor are read as a signal, with the change in output voltages representing the change in oxygen concentration.

The following chemical reactions which take place in SK-25:

Cathodic reaction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Anodic reaction: $2Pb + 2H_2O \rightarrow 2PbO + 4H^+ + 4e^-$
Total reaction: $O_2 + 2Pb \rightarrow 2PbO$

A small volume air bubble is contained inside the sensor body in order to compensate for internal influence from pressure changes. The sensor's electrolyte is primarily composed of acetic acid with a pH of approximately 6. The sensor's body is made of ABS resin.

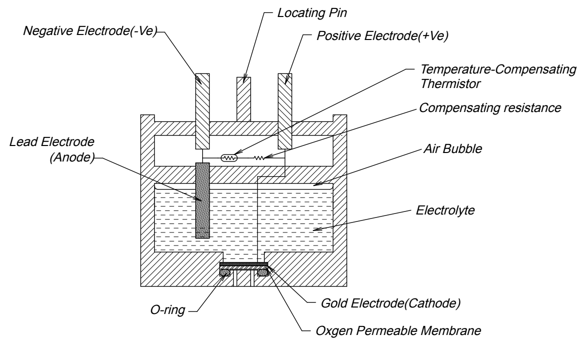


Fig. 1 - Structure of SK-25

2-4 *Specifications*

Table 1 shows the specifications of SK-25.

Item		Model SK-25
Measurement range		0~30% O_2
Accuracy (Note 1)		±1% full scale
Operating conditions	Atmospheric pressure	1013hPa ± 20%
	Temperature	-10˚~50˚C
	Relative humidity	0~99%RH (no condensation)
Response time (90%) (Note 2)		≤ 15 seconds
Initial output voltage under factory test conditions		5.5~8.5mV
Factory test conditions	Atmospheric pressure	1013hPa
	Temperature	25˚ ± 5˚C
Life expectancy at 20˚C in normal air (Note 3)		approx. 3 years

Notes:
1) When calibrated at both 0% and 30% of O_2, accuracy in the range from 0-30% O_2 shall be within ±1% of full scale.
2) Sensors should be used under conditions where the air exchange is greater than 200~300ml/minute in order to obtain the response speed as specified in Table 1.
3) Life expectancy at 20˚ ± 1˚C / 60 ± 5%RH in normal air (1013 ± 5hPa / 20.7%O_2) is defined as the period until sensor output drops to 60% of original value.

Table 1 - Specifications of SK-25

2-5 *Absolute maximum operating and storage conditions*

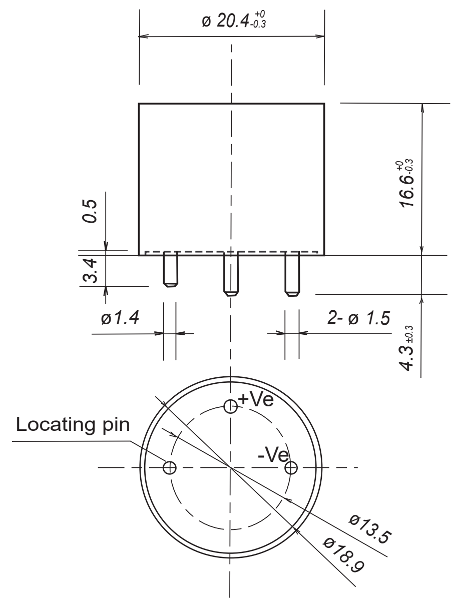
The accumulated total duration of exposure to the absolute maximum conditions listed in Table 2 should be limited to no more than 24 hours.

Item	Lower limit	Upper limit
Pressure	507hPA (Note 1)	1520hPA (Note 2)
Temperature	-20˚C (Note 3)	60˚C (Note 4)
Relative humidity	0%RH (Note 5)	100%RH

Table 2 - Absolute maximum operating and storage conditions of SK-25

<u>Cautions</u>:
1) Beneath the lower pressure limit, sensor life may become shorter due to excessive evaporation of the liquid electrolyte.
2) At pressure in excess of the upper limit, sensor output may become unstable due to excessive air entering through the o-ring.
3) In the range -10~-20˚C, the electrolyte will freeze and the sensor will not function, but SK-25 would not be damaged by freezing of the electrolyte and will resume functioning after the electrolyte thaws to a liquid state. Below -20˚C, the sensor may be damaged by freezing of the electrolyte, resulting in possible leakage of the electrolyte.
4) At temperatures in excess of the upper limit, the sensor life may become shorter than the specification due to evaporation of the electrolyte.
5) If used for a long period in an extremely dry environment, sensor life may be shortened due to excessive evaporation of the liquid electrolyte.

2-6 *Dimensions (see Fig. 2)*



u/m: mm
If not specified, all tolerances are ±0.2 mm

Figure 2 - Dimensions of SK-25

3. Typical Sensitivity Characteristics

3-1 *Sensitivity to oxygen*

Figure 3 shows the sensitivity characteristics of SK-25 The Y-axis indicates the output voltage of the sensor.

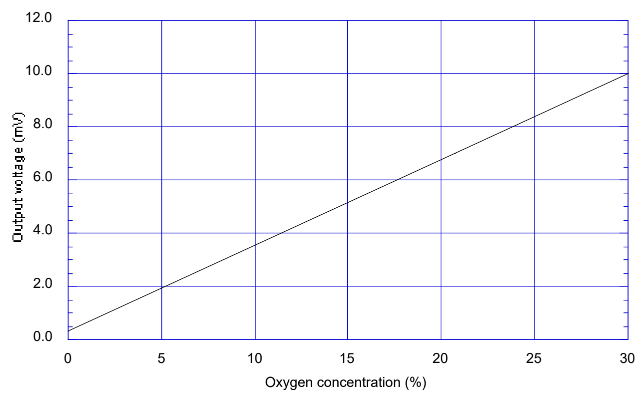


Fig. 3 - SK-25 sensitivity characteristics

3-2 *Response time*

Figure 4 demonstrates the response pattern of the sensor's output voltage. The Y-axis indicates the output voltage ratio(%) to saturated voltage. Typical response time to 90% of saturated response is 12 seconds for SK-25.

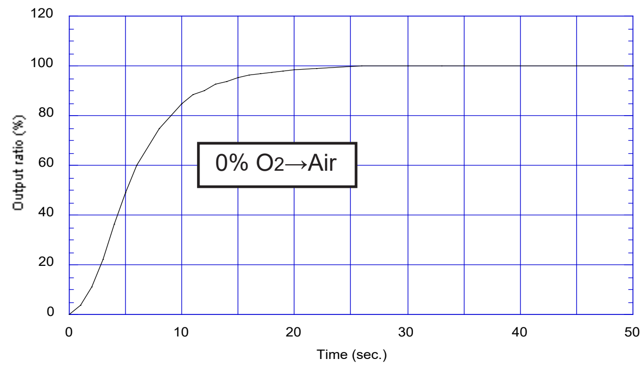


Fig. 4 - Response speed of SK-25 to oxygen

3-3 *Influence of various gases*

The influence on SK-25 from various gases is shown in Table 3. The 'interference level' shown in the table indicates output change converted into oxygen gas concentration(%). For example, if 1% NO_2 gas coexists in air at 20˚C/50%RH (20.7% oxygen), sensor output will be about 0.6% larger and the measured oxygen concentration will be 20.7+0.6=21.3%.

Gas	Concentration	Interference Level
Carbon monoxide	400ppm/air	no effect
Carbon dioxide	100%	no effect
Nitric monoxide	1%/N_2	no effect
Nitrogen dioxide	1%/N_2	0.6% over output
Sulfur dioxide	1%/N_2	no effect
Hydrogen sulfide	50ppm/N_2	no effect
Ammonia	1%/air	no effect

Table 3 - Influence of various gases on SK-25

3-4 *Effects of pressure change*

The pressure dependency of SK-25 can be seen in Figure 5. In this range of atmospheric pressure, sensor output voltage maintains a linear relationship when compared with atmospheric pressure.

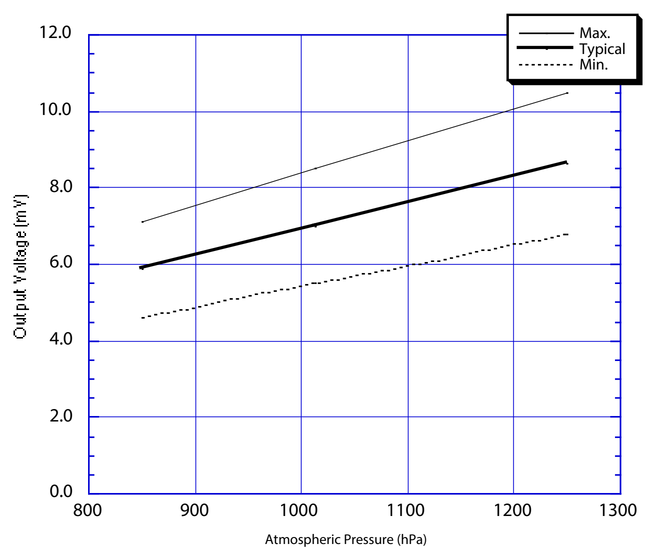


Fig. 5 - SK-25 response of output voltage to ambient pressure changes (at 25˚C/60%RH)

3-5 *Humidity dependency*

Figure 6 displays an example of humidity dependency for SK-25. The Y-axis shows ratio of sensor output voltage at various relative humidities to sensor output voltage at 60%RH. The sensor itself is not influenced by humidity. The phenomenon observed in Figure 6 is the result of the influence of humidity on O_2 concentration in air, as indicated in Figure 7.

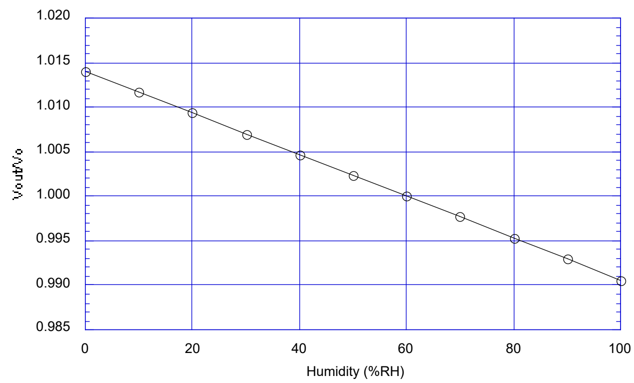


Fig. 6 - SK-25 effect of humidity on output voltage (at 25˚C in ambient air)

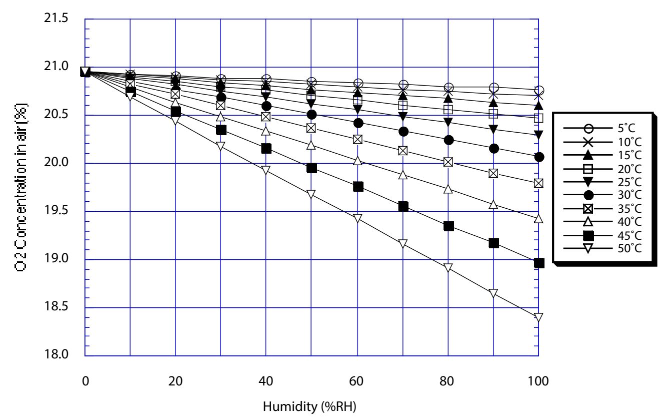


Fig. 7 - Effect of humidity on O_2 concentration in air

3-6 *Temperature dependency*

The SK-25 has a built-in temperature compensation circuit which uses a thermistor that is mounted inside the sensor's body (*see Fig. 1*). The temperature dependency of SK-25 with this built-in compensation circuit is shown in Fig. 8.

SK-25 may show some transient characteristics if the ambient temperature changes very widely and quickly. This is caused by the difference in response speed to temperature changes between the sensor compartment and the built-in thermistor. A quick rise in ambient temperature temporarily makes output voltage low and vice versa for a quick fall in temperature. Such temporary drift disappears after the sensor's temperature reaches equilibrium with the ambient temperature. For avoiding this problem, the sensor should be protected from quick temperature changes (such as direct exposure to sunlight or wind) by some kind of enclosure.

In addition, temperature should be kept uniform throughout the sensor's structure in order to avoid improper compensation caused by differences in temperature between the sensing area and the thermistor location.

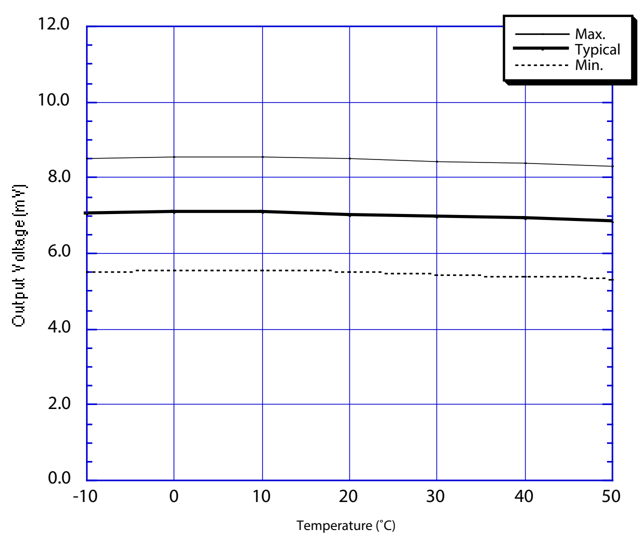


Fig. 8 - SK-25 temperature dependency of output voltage

4. Reliability

4-1 *Influence of organic solvents*

Exposure to organic solvents such as toluene, benzene, xylene, acetone, methyl ethyl ketone, methyl chloride, kerosene, gasoline, naphtha and gas oil may cause the sensor's external housing (ABS resin) to degenerate and degrade, resulting in unstable output voltage. Condensation of such solvents on the sensor would cause adverse influence on output voltage and response speed. To reduce potential risk of exposure to these solvents, installation of a filter on the sensor is recommended.

4-2 *Life expectancy*

The life expectancy of SK-25 is expressed in %-hours as follows:

[Oxygen Concentration (%)] x *[Exposure Time (hours)]*

Accordingly, the life of SK-25 is approximately 540,000 %-hours. *The end of life for SK-25 is specified as the point at which output voltage is reduced to 60% from the initial output voltage of the sensor.* These facts indicate that the expected life time in ambient conditions (21% O_2 at 20˚C) is 3 years for SK-25.

a) *Relationship between expected life and O_2 concentration*
Figure 9a shows the relationship between life expectancy and O_2 concentration for SK-25. The Y-axis indicates the ratio of life expectancy in a given O_2 concentration (L) to life expectancy at 20.7% O_2 (Lo). The greater the O_2 concentration, the shorter the life expectancy. The influence of atmospheric pressure on life expectancy is estimated based on the O_2 concentration in a given atmospheric pressure.

b) *Relationship between expected life and storage temperature*
Figure 9b shows the relationship between life expectancy and ambient temperature. The Y-axis indicates the ratio of life expectancy at a given temperature (L) compared to life expectancy at 20˚C (Lo). A correlation exists between the sensor's life time and its storage temperature—the life time becomes shorter as the storage temperature increases.

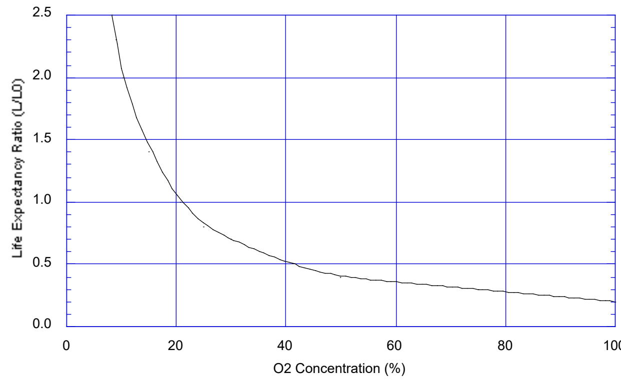


Fig. 9a - Relationship of life expectancy vs. O_2 concentration (Lo = life at 20.7% O_2)

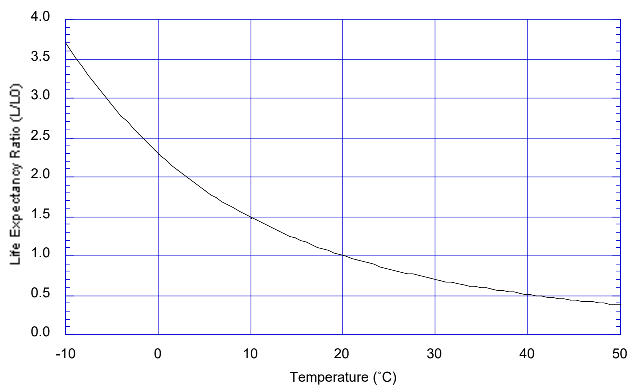


Fig. 9b - Relationship of life expectancy vs. ambient temperature (Lo = life at 20˚C)

4-3 *Long term stability*

When used in normal indoor air at uncontrolled ambient temperatures without any incidence of improper use, SK-25 shows good long term characteristics as illustrated in Fig.10.

Please note that there are various factors which may influence the life time of SK-25 in actual use and that their life span can be variable.

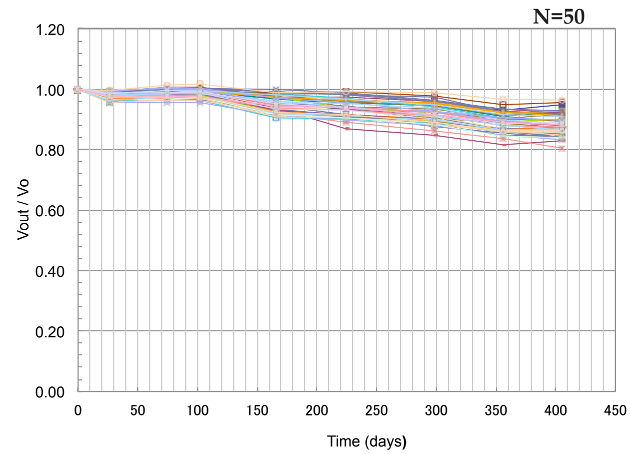


Fig. 10 - SK-25 long term stability

5. Cautions

5-1 *Required oxygen amount*

SK-25 consumes a small amount of oxygen during the detection process. It is recommended that these sensors be used under conditions where the air exchange is greater than 2ml per minute to offset the sensor's oxygen consumption. Please note that sensors should be used under conditions where the air exchange is greater than 200ml per minute in order to obtain response speed specified in Table 1.

5-2 *Mechanical strength against shock and vibration*

Since mechanical shock and vibration may potentially influence the sensitivity characteristics of the sensor, these factors should be avoided in actual usage. Temporary changes/instability in the sensor's output signal may result due to these factors, but the signal may recover to its original state after the sensor is kept motionless in natural air/room temperature for between several hours to several days. If the mechanical shock or vibration is great, an irreversible change in the output signal may occur due to structural damage within the sensor. Shock absorbing measures should be used to protect the sensor during transportation or when used for applications in which shock/vibration is likely to occur.

5-3 *Low and High O_2 concentration detection*

When less than 1% O_2 is measured, offset voltage (which appears at close to 0% of O_2) should be taken into consideration when calculating O_2 concentration. For details, please refer to the document *Application Notes on Offset Voltage and Low Concentration Measurement*.

Please note that sensors should not be stored or used continuously in a low oxygen environment below 1% for 24 hours or longer.

Do not expose the sensor to high oxygen conditions over 30% O2. If the sensor is used or stored in a condition out of the specified measurement range, output signal may change, or response speed may decrease.

5-4 *Storage conditions*

When the sensor is shipped, blue tape covers the gas diffusion holes to minimize consumption of oxygen by the sensor during storage. Before measuring sensor output, the tape should be removed.

The sensor with blue tape in place should be kept under the following storage conditions.

Oxygen concentration: Atmospheric oxygen concentration
Temperature: 10℃ ~ 35℃
Atmospheric pressure: 912~1114hPA
Relative humidity: No condensation

Please adhere to the following cautions relating to blue tape. Failure to follow them may result in reduction of expected effect by the blue tape, and/or deterioration of or damage to the sensor.
1. Keep the above storage conditions when it is stored. Do not store the sensor in a refrigerator.
2. Do not scratch the blue tape covering the gas diffusion holes, nor write anything on it with pen, marker pen etc.

3. Do not attach a sticker or other tapes on the blue tape, nor make any modifications that may prevent oxygen permeation through the gas diffusion holes.
4. Do not use the blue tape again once it is removed. After removing the blue tape, do not stick any other tapes or put a cover to close the gas diffusion holes, which may prevent Oxygen permeation into the sensor.

At -10~-20˚C, the electrolyte will freeze and the sensor will not function, but SK-25 would not be damaged by freezing of the electrolyte in this range and will resume functioning after the electrolyte thaws to a liquid state. Below -20˚C, the sensor may be damaged by freezing of the electrolyte, resulting in possible leakage of the electrolyte.

At temperatures higher than 60˚C, the sensor life may become shorter than the specification due to evaporation of the electrolyte.

5-5 *Influence of condensation*

Measures should be taken to prevent condensation on the sensor because the output signal will degrade and response speed will decrease, causing inaccurate measurement. However, once condensation dissipates, sensor characteristics will recover to their original state.

5-6 *Recommended input impedance*

The sensor must be connected to equipment which has an input impedance of 1000kΩ or greater. If not, proper temperature compensation would not be possible.

5-7 *Sensor connection*

The sensor must not have a counter-electromotive force applied to it from any equipment to which it is connected. Application of external electric potential to the sensor's output terminals may cause temporary instability in the output signal and reduced response speed. However, removal of this condition and subsequent aging in normal air for several days will allow the sensor to recover to normal.

If reverse polarity or excessive voltage is applied to the sensor, the characteristic change would be irreversible due to the internal electrical damage caused by this condition. For example, if several 10mV of reverse voltage were applied, the internal electrode would be broken.

5-8 *Safety measures for electrolyte leakage*

If the liquid electrolyte leaks due to sensor breakage, care should be taken in handling the sensor, which should immediately be placed into a plastic bag. The liquid electrolyte is a weak aqueous acid solution (pH=5~6) with an irritating odor. The liquid is non-flammable. Since this solution contains lead acetate, which is harmful to humans, contact with this liquid should be avoided.

In case the liquid electrolyte contacts the skin or clothing, wash with soapy water and rinse generously with plain water. If the liquid electrolyte contacts the eye, flush with water for at least 15 minutes and obtain immediate medical assistance. In case of breathing in of the electrolyte, flush the nasal cavity thoroughly with water and seek immediate medical assistance. If the electrolyte is swallowed, rinse the mouth thoroughly with water and seek immediate medical assistance.

5-9 *Soldering*

The sensor pins should not be soldered since the internal structure may be damaged by the heat of soldering. Pin sockets should be used for sensor connection.

5-10 *Sensor label*

The sensor label covering the sensor body should not be removed since the label is used to prevent evaporation of electrolyte from the sensor body.

5-11 *Disposal*

Spent SK-series oxygen sensors should be disposed of in accordance with applicable regional, national, and local laws and regulations.

5-12 *When designing equipment using SK-series oxygen sensors*

Sensor characteristics may be affected by environmental conditions of use, such as ambient temperature, humidity, gas pressure, flow rate, etc. Sensor performance should be evaluated under actual operating conditions before usage.

6. Limited Warranty and Limitation of Liability

The SK-series oxygen sensors shall be warranted for 12 months after the date of purchase from Figaro. Provided that return of the sensor to Figaro is made within the warranty period, if it is determined upon reasonable inspection tests that any of the following defects exists, returned sensors will be replaced free of charge with a new sensor of the identical model.

1) The output voltage of the sensor in normal air at 25˚C±5˚C, 60±5%RH and atmospheric pressure of 1013±5hPa is less than 3.3mV.
2) The output voltage change is not proportional to the change in oxygen concentration.

The warranty of the replacement sensor will continue for the warranty period of the original SK-series product.

THIS WARRANTY SHALL NOT APPLY IN THE EVENT OF FAILURE TO COMPLY WITH ANY INSTRUCTIONS OR CAUTIONS PROVIDED BY FIGARO, AND TO ANY SK-SERIES PRODUCTS OR PORTIONS THEREOF WHICH HAVE BEEN SUBJECTED TO ABUSE, MISUSE, IMPROPER INSTALLATION, STORAGE, OR MAINTENANCE, OR IMPROPER OPERATION UNDER THE CONDITIONS WHICH DEVIATE SIGNIFICANTLY FROM NORMAL AMBIENT AIR AND TEMPERATURE. IN NO EVENT SHALL FIGARO ENGINEERING INC. (“SELLER”) OR MAXELL, LTD. (“MANUFACTURER”) BE LIABLE TO PURCHASER, ITS CUSTOMER, ITS ASSIGNS OR AGENTS, FOR ECONOMIC LOSS, INCIDENTAL OR CONSEQUENTIAL DAMAGES WHETHER BASED UPON WARRANTY, CONTRACT, OR TORT INCLUDING NEGLIGENCE AND PRODUCT LIABILITY WHETHER AT EQUITY OR AT LAW, INCLUDING BUT NOT LIMITED TO ANY DAMAGES FOR WORKMANSHIP ARISING DIRECTLY OR INDIRECTLY FROM USE OF THE SK-SERIES PRODUCTS.

SK-series oxygen sensors are designed, manufactured and tested for industrial application only. The products are not designed, manufactured, tested, or intended specifically for use in or incorporation into artificial respirators, ventilators and/or other equipment for medical application, or subassembly modules or parts thereof (“Medical devices”).

Notwithstanding the foregoing above, in case that the purchaser intends to use the SK-series products for incorporation into or with the Medical devices, which is against the foregoing, the purchaser shall assume all risk for such use, and make an assessment and judgement on fitness of the SK-series products for such use in the Medical devices and on safety of the Medical devices using the SK-series products based on evaluations of reliability of the SK-series products to be carried out by the purchaser as required for such use through a thorough understanding of the contents in this Technical Information and other technical information provided by the Seller.

By purchasing the SK-series products and using them for incorporation into or with the Medical devices, the purchaser agrees to provide the Seller upon request from the Seller with valid proof of approvals and permissions required to manufacture and sell such Medical devices in accordance with applicable regional, national, and local laws and regulations.

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