Humidity measurement in air

Humidity in the form of water vapour is always present in the air. It is measured either as absolute or relative humidity. These two terms are defined as follows:

Absolute humidity of a gas mixture

The absolute humidity of a gas mixture is defined as the quantity of water vapour (kg) contained in each volume of the gas mixture. It is expressed in terms of kg water vapour per kg gas mixture.

The water vapour present in the gas mixture generates a pressure, which is part of the total barometric gas pressure. The vapour pressure and the absolute humidity cannot exceed the saturation level at a given temperature. Above this level, water is separated out in liquid form. The maximum pressure is described as saturation pressure and is highly temperature-dependent.

The absolute humidity of the air is of limited practical significance, because one essential factor, the temperature, is not taken into account in the determination of absolute humidity.

Relative humidity of a gas mixture

Relative humidity is defined as the ratio of the actual water vapour pressure to the highest possible water vapour pressure:

%rh = 100 x p/ps
p = Water vapour pressure in the gas mixture at ambient temperature
ps = Saturated water vapour pressure at ambient temperature

Therefore, 100%rh corresponds to the maximum amount of water vapour, which a gas mixture can contain. Below the saturation level, the water vapour pressure p and hence also the relative humidity (% rh) are proportional to the total barometric pressure. Since the highest possible water vapour pressure ps is extremely temperature-dependent, the relative humidity is also temperature-dependent. The relative humidity therefore decreases, when the temperature rises, and vice versa.
Influence of temperature fluctuations of ±1 °C at various temperatures and humidities:

% rh	10 °C	20 °C	30 °C	50 °C	70 °C
10 %rh	±0.7%	±0.6%	±0.6%	±0.5%	±0.5%
50 %rh	±3.5%	±3.2%	±3.0%	±2.6%	±2.3%
90 %rh	±6.3%	±5.7%	±5.4%	±4.6%	±4.1%

It is extremely important that the probe and the sample to be measured have the same temperature to achieve useful measurements.

To gain a better understanding of the relationships, we refer to the h-x diagram of humidity in air (Mollier's diagram). This illustrates clearly the relationship between temperature, moisture content and relative humidity.

Relative humidity below 0 °C

At temperatures below 0 °C, the saturation pressure above water in liquid form (supercooled): e_w differs from the saturation pressure above ice: e_i.
e_w = Water vapour saturation pressure above water at ambient temperature
e_i = Water vapour saturation pressure above ice at ambient temperature

T	e_w	e_i	% rh
°C	hPa	hPa	–
0	6.11	6.11	100
–5	4.22	4.02	95
–10	2.87	2.60	91
–15	1.91	1.65	87
–20	1.26	1.03	82
–25	0.81	0.63	78
–30	0.51	0.38	75

For this reason, a measurement of 75%rh at -30°C corresponds to saturation (100%rh) above ice.

Humidity measurement in solids

Similar to gases, solids such as paper or food can also absorb and retain water or desorb it. Materials with this property are called hygroscopic. Depending on the point of view, there are two different observations that characterise the humidity state of a material.

Water content

The water content of a material is the amount of water contained in the material, expressed in percentage of weight. This aspect is interesting for situations, where a material is sold by weight. However, if we talk of the physical properties of a material, then the water content is of no interest, as it provides no meaningful information.

Equilibrium humidity

A hygroscopic material tries to establish equilibrium of its humidity with that of its environment. The presence of water in the material produces a water vapour pressure (pm) on the material surface. If this pressure (pm) is equal to the water vapour pressure (p) of the ambient atmosphere, then the material achieved equilibrium humidity with its environment. Any difference between the pm and the p produces a water exchange and therefore a change of the water content of the material concerned, until equilibrium is achieved.

Equilibrium humidity of a material is therefore defined as the relative humidity of the ambient atmosphere that has to prevail in order to cause no exchange of water.

Water activity

The relative humidity, which must prevail in the surrounding atmosphere to avoid water exchange between material and air, is defined as water activity. It is practically the same as the equilibrium humidity of a material in the definition, but is not stated in 0….100%, but in 0…1Aw. The water activity is a measure of the degree of freedom of the water retained in various ways in a material.

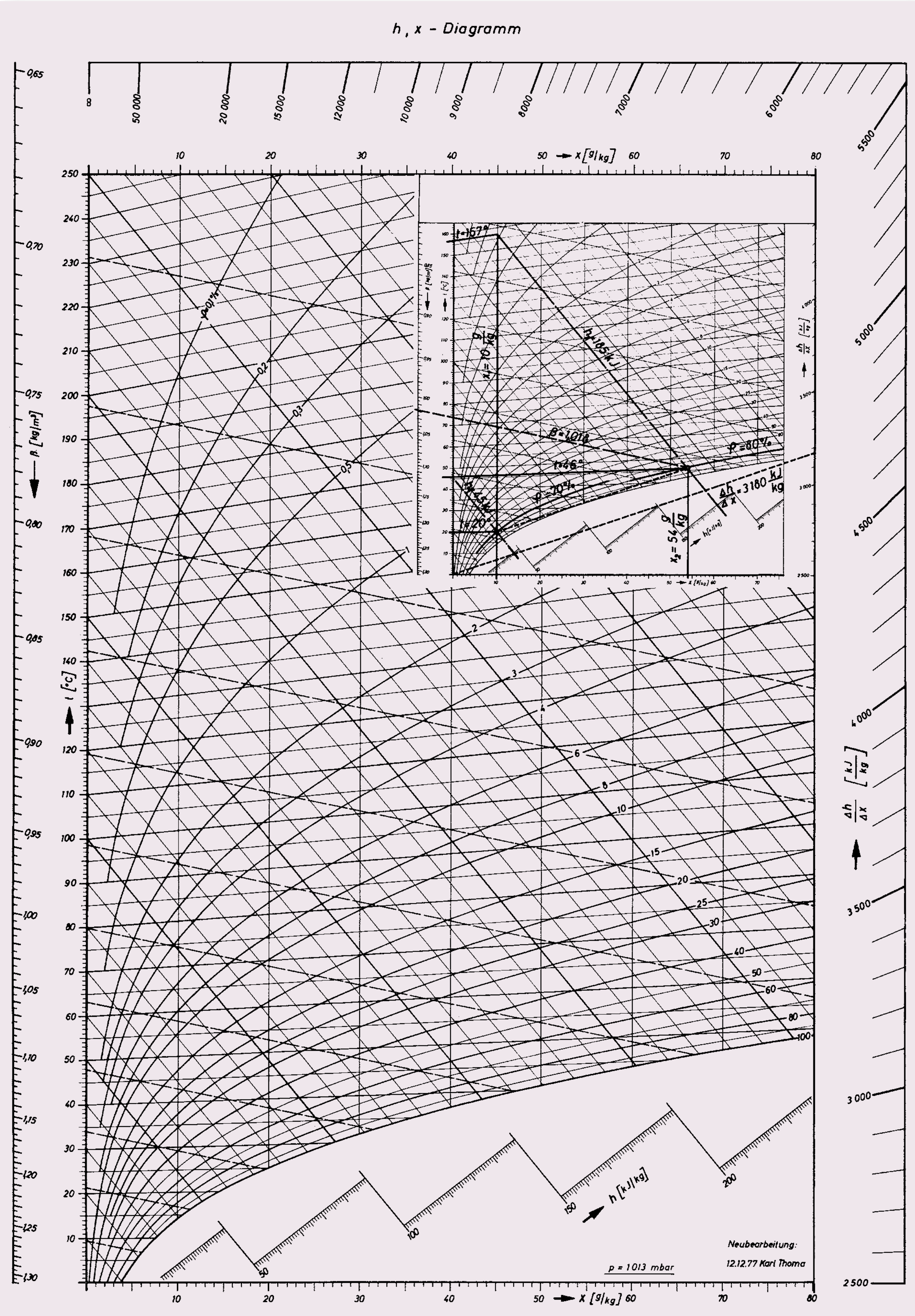
The water activity directly determines the physical, mechanical, chemical and microbiological properties of the material as well as interactions, such as pourability, lump formation, cohesion, static electricity, etc. In the food industry, water is a highly significant factor in the shelf life of semi-finished and finished products.

Sorption isotherms

At equilibrium, the relation between water content and equilibrium humidity of a material can be displayed graphically by a curve, the so-called sorption isotherm.

For each humidity value, a sorption isotherm indicates the corresponding water content value of the material at a given, constant temperature. If the composition or quality of the material changes, then its sorption behaviour also changes. Because of the complexity of sorption processes, the isotherms cannot be determined by calculation, but must be recorded experimentally for each product. Therefore in practice, water content and water activity should be viewed as two independent parameters.

h-x diagram


h , x - Diagramm
t [°C]
β [kg/m³]
x [g/kg]
h [kJ/kg]
Δh/Δx [kJ/kg]
p = 1013 mbar
Neubearbeitung:
12.12.77 Karl Thoma
t=167°
h₂=105 kJ
x₁=10 g/kg
x₂=54 g/kg
β=1,018
t=46°
φ=70%
φ=80%
h=45 kJ
t=20°
Δh/Δx = 3180 kJ/kg

Explanations to the h-x diagram

1 Explanations of characters

1.1 ß: Dry air quantity in kg per m³ process air
1.2 t: Temperature of the process air in °C
1.3 x: Water vapour content in g per kg dry air of the process air
1.4 h: Heat content (enthalpy) in kJ per kg dry air of the process air
1.5 φ: Relative humidity of the proces air
1.6 $\frac{\Delta h}{\Delta x}$: Heat consumption in kJ per kg water

NB: We designate prcess air as air in different states, as found during drying (fresh air/warmed air from the furnace and/or a heater/conditioned air, also exhaust air).

2. Use of the h-x diagram

2.1 Dry air porition ß in kg per m³ process air

Example:
Measured values of the exhaust air in a drying plant tA = 46 °C; φ = 80 %rh;
exhaust air quantity 12000 m³/h
The line drawn parallel to the dotted lines of the diagram through the status point of the exhust air (Intersection of the t-line 46 °C and the humidity curve 80%) results in its extension at the Intersection with the left margin scale at ß = 1,018 kg dry air per m³ of this exhaust air. At 12000 m³/h, the dry air quantity is thus 12000 · 1,018 = 12200 kg/h.

2.2 Water vapour content in g per kg dry air of the process air

2.2.1 The vertical line drawn through the status point (in our example 46 °C; 80 %rh) results at the intersection with the horizontal abscissa a water vapour content of x_2 = 54 g per kg dry air of this exhaust air.

2.2.2 If the hot air fed into the drying chamber is created by heating outside air (in the example temperature 20 °C; 70 % rh) this hot air brings x_1 = hot water per kg dry air with it (determined of x_1 = 10 g hot water per kg dry air with it (determination of x_1 as described in 2.2.1]). this means that each kg of dry air has absorbed $\Delta x = x_2 - x_1 = 44$ g Wasser aufgenommen hat.

2.2.3 With 12200 kg dry air/h, 12200 · 0,044 = 536,8 kg water are withdrawn from the product being dried per hour.

2.3 Heat content inkJ per kg dry air of the processed air.

2.3.1 The line drawn parallel to the lines of equal heat content (h lines) through the status point (in our example 46 °C; 80 % rh) results on the one hand at the intersection with the inclined abscissa in a heat content h_2 = 185 kJ/kg dry air of this exhaust air.
(Conversion to kcal: 1 kcal = 4,1868 kJ).
On the other hand this extended parallel line in the upper part of the diagram helps to determine the approximate hot air temperature (see 2.5) for this heat content.

2.3.2 The heat content of the outside air (in our example 20 °C; 70%) is h_1 = 45kJ, (determined as described in 2.3.1) so that heating by $\Delta h = h_2 - h_1 = 140$ kJ per kg dry air is necessary for drying.
However, the actual heating must be higher than this Δh, due to various heat losses such as radiation, heating of the goods to be dried, the drying cars and frame etc. But for well insulated plants, no more than 15 kJ/kg dry air.

2.3.3 The theoretical heat consumption in our example is thus:
12200 · 140 = 1,708 million kJ/h.

2.4 Theoretically required heat quantity per kg of expelled water:
The parallel line drawn through the zero point to the connecting line of the status points for outside air and exhaust air indicates the theoretical heat consumption at the intersection with the right margin scale:

$\frac{\Delta h}{\Delta x} = 318 \ \frac{kJ}{kg}$ theor. heat consumption per kg H_2O

calculation:

$$\frac{\Delta h \text{ (from 2.3.2)}}{\Delta x \text{ (from 2.2.2)}} = \frac{140}{0{,}044} = 3182 \ \frac{kJ}{kg}$$

2.5 Hot air temperature
The vertical line drawn through the status point of the outside air (see 2.2.2) intersects with the h line of the exhaust air (see 2.2.1) at a particular point. If one draws a line through this point parallel to the lines of equal temperature (t lines), one obtains the theoretically required hot air temperature at the intersection with the ordinate, in our example 157 °C.

Theory

Humidity definitions

Relative humidity (%rh)
Is defined as the ratio of the quantity of water vapour present in the air to the maximum possible water vapour at the same temperature.

Dew point (Dp)
The dew point is that temperature, where gas being cooled, begins to condense water vapour into liquid water. The dew point may also occur below 0°C (super-cooled water). This point has to be distinguished from freezing point (see below).

Frost point (Fp)
The frost point is that temperature, where gas being cooled begins to condense water vapour in the form of ice. Freezing point occurs only at temperatures below freezing.

Water vapour density (Dv) in g/m^3
This is the ratio between the mass of the water vapour to the volume of the gas mixture, in which the water vapour is.

Water vapour content (Q) in g/kg
This is also called specific humidity and is the ratio between the mass of the water vapour to the mass of the gas mixture, in which the water vapour is.

Mixing ratio (R) in g/kg
This is the ratio of the mass of the water vapour to the mass of the dry gas mixture, in which the water vapour is.

Water vapour partial pressure (E) in hPa
This is the pressure of the gaseous phase of the water in a gas mixture.

Water vapour saturation pressure (Ew) in hPa
This is the maximum pressure that the water vapour can reach at saturation for the appropriate temperature.

Enthalpy (H)
Enthalpy is the measurement for the determination of the energy required, to change the gas mixture from a certain temperature/humidity state to another. Enthalpy is not used as an absolute value, but as the difference between two points of particular interest. The choice of 0 °C and 0 %rh for zero enthalpy was arbitrary.

Mixing ratio/Volume (PPMv)
This is the relationship between the number of water vapour molecules to the number of molecules of the other components in the gas. Once this value is determined, it does not change with pressure or temperature.

Common faults/remedies
Not only humidity, but also many other physical parameters are measured in industrial processes. The most important are temperature, pressure, air speed, etc. The measurement of humidity is different to other parameters in one important aspect, namely that humidity cannot be considered as an absolute value, because the measuring principle is based on the exchange of water vapour between the sensor and the surrounding gas or gas mixture, e.g. air.

In our capacity as experienced manufacturer, we are well aware of our responsibility to provide our customers with instruments, that will withstand even the most demanding operating conditions and which are at the same time easy to use and require little maintenance. However, we wish to remind our customers, that our instruments will provide an excellent service and provide accurate results, if the following list of simple operation and maintenance instructions are followed:

1. Analysis of the measuring medium, in which the probe is to be used. What suspended matter and/or chemicals are present and in what concentration?
2. The probe should be mounted at the correct measuring location, and not where it is most convenient.
3. In case of doubt please contact your ROTRONIC representative.
4. The filter has to be changed regularly, if the probe is used in demanding environments. ROTRONIC filters can be cleaned in an ultrasonic bath with suitable detergents. However, it is advisable to keep a spare set in stock.
5. The perfect function of the sensor should be checked every 6 to 12 months.
6. Calibration of the sensor can be performed by the user with the help of the SCS certificated humidity standards, supplied by ROTRONIC. Calibration of the instruments will ensure, that your measurements are always verifiable.

ROTRONIC Humidity sensors

With the HYGROMER® series, ROTRONIC provides the most advanced capacitive polymer sensor system for relative humidity measurement. It is the sensor with the largest temperature range (-50…200 °C) available on the market. This measuring principle is recognised internationally and is based on the change of the dielectric properties of a polymer as a function of the prevailing relative humidity. The polymer used for the HYGROMER® sensor is hygroscopic and has a natural tendency towards equilibrium with the humidity environment which surrounds it. A corresponding water vapour pressure is formed at the surface of the polymer depending upon the temperature and the amount of water absorbed into the polymer. Any difference between this water vapour pressure and the water vapour pressure of the environment is balanced by an exchange of water molecules until the two are equal. These changes are measured electrically, amplified and indicated as relative humidity. The amount of water which is absorbed into the polymer is determined by the ambient humidity and temperature, thus the resulting dielectric properties of the sensor reflect the percentage relative humidity (%rh) to which the sensor is exposed.

For many years, the ROTRONIC HYGROMER® C94 was the best sold sensor. With the disappearing of the Hygrolyt sensors, new elements were developed in order to even better fulfil the customers requirements. An industry sensor does not necessarily need the same properties as a sensor for Water Activity or a sensor for high-humidity applications. The new sensors represent the results of a continuous research and development.

Sensor Designation	Used for	Improvements:
HYGROMER® IN-1 Temperature range: -50...200 °C	Industry applications Meteorology Food technology Laboratories Cold rooms Drying processes Incubators	Gold connectors, better chemical resistance, no corrosion after condensation
HYGROMER® AC-1 Temperature range: -30...100 °C	HVAC applications Cold rooms Storage and transport Wine cellars Greenhouses Museums Churches	Better chemical resistance, better Long-term-stability
HYGROMER® WA-1 Temperature range: -30…100 °C	Water Activity- applications Food/pharma quality assurance Product stability Shelf life determination	Optimised dimensions for minimal chamber volume, Very little hysteresis
HYGROMER® RS-70 Temperature Range: -50…180 °C	High humidity- applications Cheese stocks Meat processing Tropical greenhouses Test environments Climatic chambers	Heated sensor, no condensation, better accuracy in high range of humidity
HYGROMER® RS-20 Temperature range: -50…180 °C	Brick- and tile making Wood-industry	Mechanical stability Fast response

HYGROMER® humidity sensors are always fitted to a probe or instrument. Thanks to the ROV interface, probes and instruments with HYGROMER sensors can be connected to any display unit with ROV input. (10 mV/ °C and 10 mV/%rh)

Characteristics of the sensor

Response time/Time constant

The time constant of a sensor is defined as the time required to perform 63% of a humidity change. The time constant is larger at low temperature, low air movement and high humidity. The time constant also increases when a filter is used. The filter reduces the airflow over the sensor and a slower diffusion of water molecules results in a slower response time. Therefore humidity equilibrium is reached after an extended period of time.

Reproducibility

The specifications stated refer to a humidity cycle of 10-95-10 %rh.

Theory

Pollutant table

The following gases have, in the given concentrations, no or little influence on the sensor and the humidity measurement. The data is only a guide. The resistance of the sensor depends strongly on the temperature and humidity conditions and the duration of the exposure to the pollutant.

Allowed fault caused from the pollutant: ±2 % rh

Pollutant	Formula	Maximum Workplace Concentration		Allowed Concentration Continuous Operation	
		ppm	mg/m^3	ppm	mg/m^3
Acetic acid	CH3COOH	10	25	800	2000
Acetone	CH3COCH3	1000	2400	3300	8000
Ammonia	NH3	25	18	5500	4000
2-Butanone (MEK)		300	1200		150000
Chlorine	Cl2	0.5	1.5	0.7	2
Ethanol	C2H5OH	1000	1900	3500	6000
Ethyl acetate	CH3COOC2H5	400	1400	4000	15000
Ethylene glycol	HOCH2CH2OH	100	260	1200	3000
Formaldehyde	HCHO	1	1.2	2400	3000
Hydrochloric acid	HCl	5	7	300	500
Hydrogen sulphide	H2S	10	15	350	500
Isopropanol	(CH3)2CHOH	400	980	4800	12000
Methylethylketon	C2H5COCH3	200	590	3300	8000
Nitrogen oxides	NOx	5	9	5	9
Ozone	O3	0.1	0.2	0.5	1
Sulphur dioxide	SO2	5	13	5	13
Toluene / Xylene	C6H5CH3	100	380	1300	5000
Xylol	C6H5(CH3)2	100	440	1300	5000

Practical limits

The specified operating ranges must be complied with, otherwise significant errors can arise or the measuring element could be destroyed.
A replaceable dust filter must be used in dusty environment.
Oil and grease vapours will damage the sensor, as they can condense on the sensor and thus prevent or inhibit response (insulating layer). Flue gases can therefore not be measured .
A filter must be used at air velocities above 3 m/s. The sensor must also be protected mechanically from the high air velocities above 40 m/s (for filters, see general accessories).

Sensor properties HYGROMER®

Operating range	IN-1	AC-1	WA-1	RS-20	RS-70
Humidity	0…100 % rh				
Temperature in °C	-50…200	-30…100		-20…180	
Air velocity in m/s without ohne Sensorschutz	3 m/s				
Air velocity in m/s with sensor protection sensor protection	20 – 40 m/s				
Output signals	capacitance range				
Reproducibility	better than 0.5 % rh				
Long-term stability	<1 % rh/12 months				
Time constant at 1m/s air speed	<12 s				
Typical operating lifetime	>10 years				
Saturation resistance	fully recovers after exposure				
Pressure dependence	no				
Maintenance interval	depends on application				
Energy requirement/stability	none/immediately stable				10 mW, adaptation time

Alphabetical Index

ROTRONIC On-Line Shops

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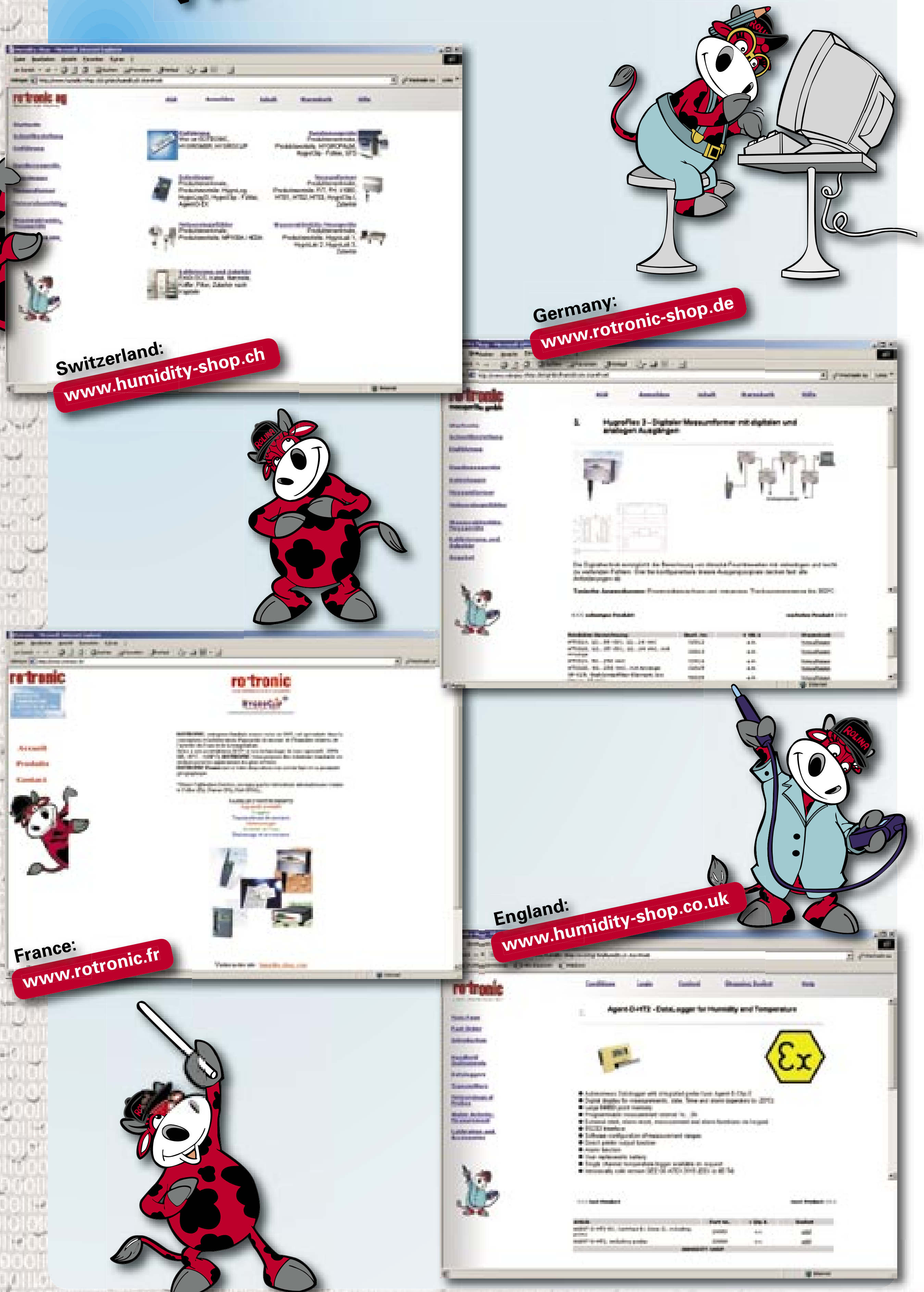

General Conditions of Sale and Supply

1. General

1.1 These general conditions of sale and supply shall be binding when such have been stated as being applicable in an offer or confirmation of order of and by ROTRONIC AG.

1.2 Orders shall only become binding upon ROTRONIC AG after it has issued a written confirmation of order.

2. Prices

Prices shall be deemed net plus V.A.T. transportation and packaging charges. provided that alternative conditions have not already benn agreed. ROTRONIC AG however hereby reserves the right to make price adjustments to cover definite increases in costs as for example the cost of wages, goods and materials.

3. Delivery period

The delivery period shall be the date laid down in the contract of sale and such may be extended should difficulties arise that may have been caused by act of God or force majeure such as war, epidemics and among other things storm and tempest.

4. Despatch

All deliveries shall be effected for the account and the risk of the customer. Any complaints concerning damage, loss or delay are to be reported to ROTRONIC AG within 8 days after the receipt of the consignment; but complaints concerning any faulty packaging shall be rendered on the same day as the receipt of the consignment.

5. Works deliveries

Should the consignment and invoicing be directly effected by the works supplier of ROTRONIC AG the conditions of sale and supply of that particular works supplier shall be valid for customers in respect of that particular contract. In such cases, these present conditions of sale and supply shall have no validity and damage indemnity claims or claims of any other nature cannot be made enforcable against ROTRONIC AG hereunder.

6. Return of goods and materials

The return of goods and materials shall require the written permission of ROTRONIC AG and may only be effected if the goods and materials are in irreproachable condition and still in their original packaging, and only then if such are usually maintained in stock by ROTRONIC AG. A copy of the delivery note or the invoice must be enclosed. Returns without either a copy of the delivery note or the invoice will not be accepted. An appropriate surcharge will be levied by ROTRONIC AG on the purchaser to defray the cost of any inconvenience caused.

7. Settlement

Invoices are to be settled net within 30 days without any deductions. Purchasers will be charged the usual bank overdraft rate of interest in respect of overdue payments.

8. Retention of ownership rights

All goods and materials supplied shall remain the property of ROTRONIC AG until full payment of the debited invoice amount shall have been received. The purchaser and the holder of the goods and materials shall in addition be under a duty hereunder to contract insurance cover for the goods and materials and, in their capacity as the insured, to assign any insurance claim of the purchaser to ROTRONIC AG.

9. Warranty

ROTRONIC AG will grant a warranty for plant and equipment for a period of 24 months form the date of delivery in respect of any evidenced faulty workmanship and materials. Should a delivered consignment prove to be contrary to contract upon inspection, the customer shall grant ROTRONIC AG the opportunity hereunder of removing the fault, or else the customer may demand replacement. Should the supply or delivery of any improvement or replacement not prove possible, the customer may choose between having the purchase price reduced or in demanding the contract of sale to be rescinded (conversion).
Damage resulting from natural wear and tear, act of God, force majeure, non compliance with the operating instructions shall be excluded from the warranty as well as mechanical interference by the customer or by third parties with plant and equipment of ROTRONIC AG without its written permission.

10. Cancellation

Cancellation of orders shall only be possible hereunder with the written approval of ROTRONIC AG. Any costs which shall have already been incurred or price increases as a result of reduction sin amounts ordered shall be for the account of the purchaser. Partial supplies of an order contracted upon call shall be claimed within the agreed supply and delivery periods, otherwise ROTRONIC AG may cause the relative consignment and invoice billing there fore to be made.

11. Place of jurisdiction

The place of jurisdiction shall be either our company's or your Swiss domicile. Legal relationship hereunder shall be subject to Swiss Law.

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