

***OZONE SCIENCE & ENGINEERING SPECIAL ISSUE ON
QUALITY ASSURANCE IN OZONE PRACTICE
(1998)***

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***Introduction by Willy J. Masschelein, President of the Quality Assurance
Committee of IOA.***

**TECHNOLOGICAL AND INDUSTRIAL OZONE IS, AND HAS ALWAYS
BEEN IN CONTINUOUS PROGRESS.**

In the late 1980s, the IOA published recommended guidance documents in the form of codes of good practice related to ozone generation and application. These still apply. However, at that time, the concentration of "industrial" ozone generated in air was currently about 20 g per normal cubic meter; exceptionally 50 g per cubic meter gas (NTP); and 60g, exceptionally up to 80-100 g ozone per cubic meter gas (NTP) when oxygen was used as feed gas for the generation systems. Since that time, progress has been made in generating higher ozone concentrations in the process gas for different applications. At present, concentrations of 200-220 g per Normal Cubic Meter (NTP) are currently obtained and the trend is to increase the concentration as far as possible.

As a consequence: a first series of revised guidance documents have been formulated by the Quality Assurance Committee and are published herewith on behalf of the Committee.

I have to thank herewith, all the members and contributors to/of the International Committee and however in particular: Dr Lutz Blaich, Dr Bruno Langlais and Ing. Eric Thieblin for the long and patient work accomplished to formulate an up-dated list of standard terms related to ozone practice.

(For *Information*: This list will also later be made available in French and German as well, and, if possible later as well in other languages).

Particular gratitude of the Committee goes also to John Bell and Anne Reading to have "formatted" a very easy and handy table of conversion of units of measurement and expression of results. The Committee will also suggest to the board other appropriate ways for diffusion of these tables as well.

Besides these, the present publication reports on several guidance methods reviewed by the QAC.

- Iodometry as a reference method for determination of ozone *concentration* in the gas phase (up to concentrations of 200g/m³ (NTP).
- Nitrite-to nitrate oxidation as a calibration method of further "on-field" methods of measurement or monitoring of ozone in water (up to concentrations of 1 mg/L).
- Colorimetric methods for control of ozone residual concentrations in water (up-dated).
- UV-absorption methods for monitoring ozone concentrations in the gas phase (up to concentrations of 200 g/m³).
- List of reference terms related to ozonation practice.
- Conversion table of units specifically related to ozonation practice.
- *Publication in OS&E (as an *annex*), of the extended summaries on the methods of analysis of ozone, as presented at the World Congress in Kyoto.
- Questions for comments and suggestions by IOA Members "at large" on measurement of "high" ozone concentrations; both in the gas and the liquid phase are very welcome.

Dr Willy J. Masschelein
President of the Quality Assurance Committee

BRUSSELS, JULY 10-1998

Résumé

LE PROGRES DE L'OZONE INDUSTRIEL ET SES APPLICATIONS TECHNIQUES A TOUJOURS ETE UN PROCESSUS CONTINU

A la fin des années 80, l'IOA a publié une série de recommandations, sous forme de codes de bonne pratique concernant l'ozone et ses applications. Elles sont toujours valables.

Cependant, à cette époque, la concentration de l'ozone généré "industriellement" était généralement de 20 g par mètre cube, exceptionnellement 50 g par mètre cube en utilisant de l'air et couramment 60 g, exceptionnellement 80-100 g d'ozone par mètre cube (PTN) en employant de l'oxygène.

Depuis lors, il y a eu des progrès dans la génération de l'ozone. Des concentrations plus élevées sont atteintes, et ce pour différentes applications. A présent, des concentrations jusqu'à 200-220 g/m³ à Température et Pression Normales sont obtenues couramment, et la tendance est d'accroître la concentration autant que possible.

Par conséquent, une première série de documents guides a été mis au point par le Comité d'Assurance de Qualité. Ils sont publiés ici par le Comité.

Je dois remercier tous les membres et collaborateurs du Comité, et, en particulier Dr. Lutz Blaich, Dr. Bruno Langlais et Ing. Eric Thiéblin pour le travail d'envergure ayant requis beaucoup de patience: l'élaboration d'une terminologie standard applicable à l'ozone et sa mise en oeuvre. (Une version en langue française et allemande sera disponible sous peu).

Notre gratitude particulière va en outre à John Bell et Anne Reading qui ont mis au point un tableau de conversion d'unités de mesure et d'expression des résultants. Etant très pratique à l'emploi, le Comité suggérera au Conseil de l'IOA différentes voies pour la diffusion de ces tableaux à l'usage des membres.

Dr. Willy J. Masschelein

Président du Comité Assurance Qualité

Zusammenfassung

DIE TECHNISCHE UND DIE INDUSTRIELLE ANWENDUNG VON OZONE BLEIBT IN EINER STETIGEN WEITERENTWICKLUNG

Ende der achtziger Jahre veröffentlichte IOA empfohlene Richtlinien-Dokumente in Form von vereinheitlichenden Regeln oder von Listen (Codes) für eine rechte Handhabung, die sich auf die Erzeugung und die Anwendung von Ozon bezogen und noch immer in Gebrauch sind.

Damals jedoch war die allgemein aus Luft "industriell" erzeugte Ozonkonzentration ungefähr 20g, höchstens 50 g/m³ (NTP); bei Einsatz von Sauerstoff was allgemein 60 g, ausnahmsweise 60 bis 100 g/m³ (NTP) erreichbar

Seit dieser Zeit hat die Herstellung hoher Ozonkonzentrationen als Prozeßgas für unterschiedliche Anwendungen Fortschritte gemacht. Gegenwärtig werden allgemein Konzentrationen von 200/l bis 220/l g/m³ (NTP) erhalten, und der Trend geht dahin, die Konzentrationen so weit wie möglich zu steigern.

Konsequenter Weise wurde eine erste Serie von revidierten Richtlinien-Dokumenten von dem Qualitätssicherungsausschuß formuliert und hiermit im Auftrag des Komitees publiziert.

Ich danke hiermit allen Mitgliedern und Mitarbeitern des internationalen Komitees und im besonderen jedoch; Dr. Lutz Blaich, Dr. Bruno Langlais und Ing. Erich Thieblin für die lange und geduldig ausgeführte Arbeit, eine zeitgemäße Liste von Standard-Begriffen in Bezug auf die Ozonpraxis zu formulieren.

Dr. Willy J. Masschelein
Präsident des Qualitätssicherungskomitees im IOA

I. IODOMETRIC METHOD FOR THE DETERMINATION OF OZONE IN A PROCESS GAS.

INTERNATIONAL OZONE ASSOCIATION Revised Guideline Document - 1998

OBJECT. The present standard method concerns the determination of ozone in air, oxygen or other process gases.

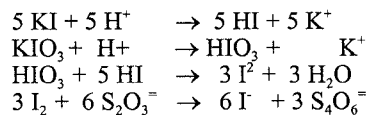
RANGE OF APPLICATION The method is directly applicable in the range of 1g/m³ to 200 g/m³ of ozone, the volume being expressed at NTP (Normal Temperature and Pressure conditions, which equal to: 0 °C or 273.15 K and 1.01325 x 10⁵ Pa or 1 Atm).

REAGENTS (all of analytical grade)

- Quality of the water for make-up of solutions shall comply with ISO Nr 3696-1987 Grade 1).
- Buffered KI (potassium iodide) in water: KI 20g/L; Na₂HPO₄·2H₂O (disodium hydrogenophosphate) 7.3g/L and KH₂PO₄ (monopotassium dihydrogenophosphate) 3.5 g/L.
- Sodium thiosulfate: Na₂S₂O₃ 0.1 mol/L in water.
- Acidifying solution: H₂SO₄ (sulfuric acid): 4.5 mol/L
- Powdered KIO₃ (Potassium periodate).
- Crystalline KI.
- HCl (hydrochloric acid) or H₂SO₄ 0.1 N (certified).
- Starch indicator: ZnI₂ (zinc iodide)-starch, prepared by dispersing 4g starch into an aliquot of water. The dispersion is added to a solution of 20g ZnCl₂ (zinc chloride) in 100 mL water. The solution is boiled until the volume has been reduced to 100 ml and is finally diluted to 1L while adding 2g of ZnI₂. The indicator is stable for at least one month when stored in the dark at room temperature.

STANDARDIZATION OF TITRANT.

Principle:



Procedure:

To 50 mL of water in a 250 ml conical flask (Erlenmeyer) are added 0.05 g KIO₃ and 0.5 g KI, followed by an other volume of about 50 mL water. After mixing, 10 mL of

certified 0.1 N acid are added. The iodine formed is titrated with the thiosulfate solution.

Results:

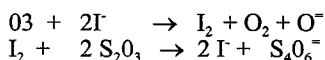
Normality of $S_2O_3^{2-}$ equals : Normality of acid multiplied by the volume of acid (mL) and divided by the volume of thiosulfate titrant (mL).

DETERMINATION OF OZONE

Procedure:

- 200 mL of KI solution are added to a gas washing bottle equipped with an open gas bubbling device (tube or diffuser) under a reagent depth of 15 cm, or more; (The use of fritted-glass diffusers is not recommended).
- A second identical flask is connected in series as a guard detector for ozone transfer and reaction in the first flask.
- Process gas containing ozone is bubbled at a flow rate of 1L/minute or less, until a total (estimated or expected) quantity of approximately 1 mM O_3 (it equals 0.048g) has passed.
- The iodine formed in the solutions of KI in the flasks immediately after acidification with 5 mL of the acidifying reagent, is titrated with a freshly standardized sodium thiosulfate solution.
- After titration to a pale yellow color, optionally, 0.5 mL of the starch indicator solution can be added to complete and record the final result. (This addition is recommended, but can be optional, depending on the skill and experience of the operators).

Results:



Concentration of ozone in g/L equals to: $24 \times \text{Volume of thiosulfate in L} \times \text{Normality of thiosulfate divided by the inlet volume of gas passed in L}$.

PRECAUTIONS

- All upstream transfer and pressure reducing equipment must be in materials which do not react with ozone, e.g. glass, PTFE, ...
- The gas contacting systems must have a free exit to ambient pressure.
- All gas flow must be expressed at NTP, (for high precision or when analyzing high ozone concentrations, the volume must be corrected for local existing atmospheric pressure).
- Gas flows should be measured with an accuracy of 1%: totalizing volumetric gas meter or with a bubble trap).

PRECISION AND ACCURACY

- Detection limit of the analytical procedure: 0.1 mg/L
- Repeatability: 2% of the measured ozone concentration.

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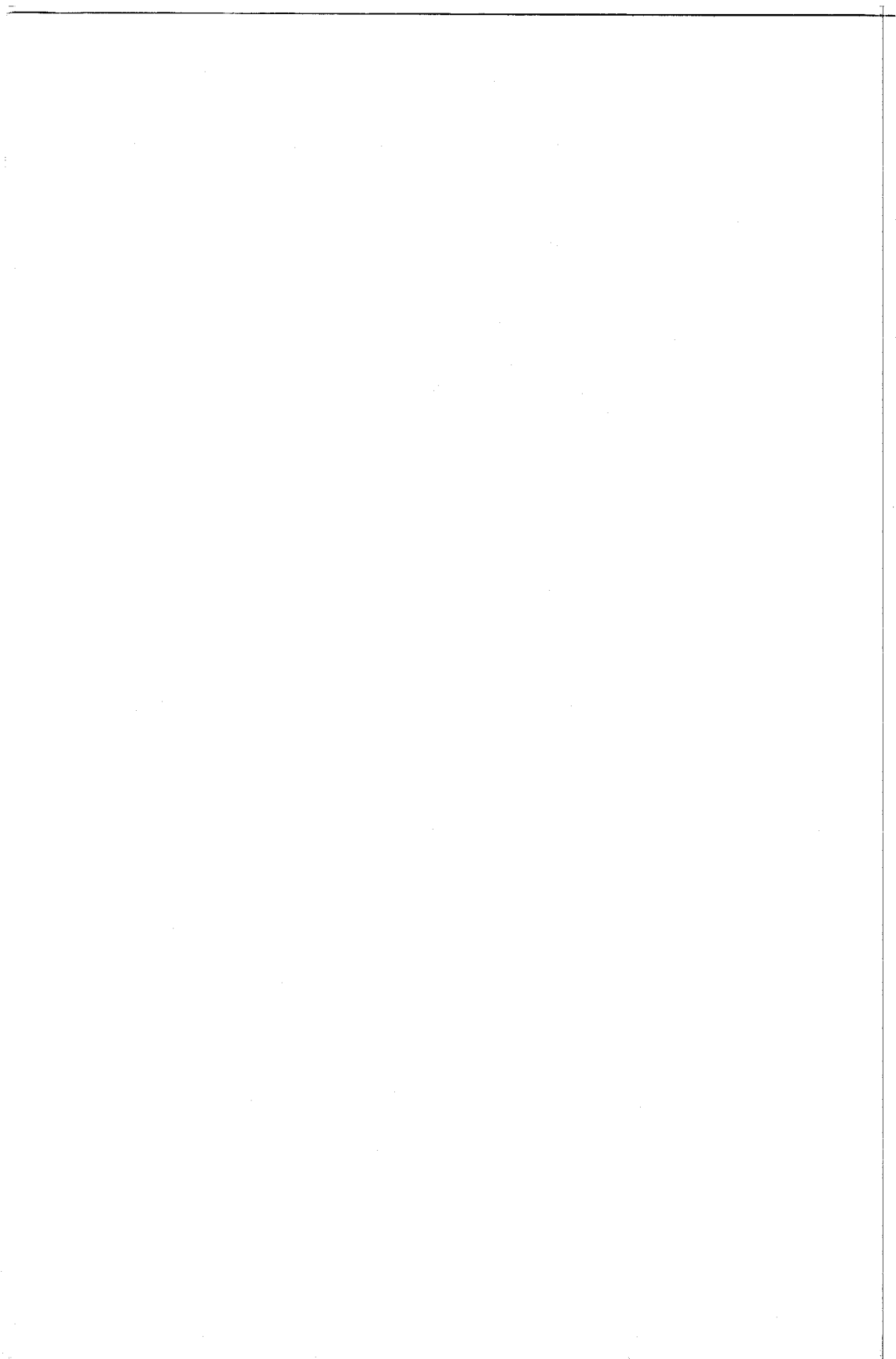
INTERFERENCES

Nitrogen oxides, other oxidants of iodide if present.

MAILING ADDRESS FOR COMMENTS.

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II. INTERCALIBRATION OF ANALYTICAL METHOD AND MONITORING OF DISSOLVED OZONE.

INTERNATIONAL OZONE ASSOCIATION Revised Guideline Document - 1998

Principle: Excess nitrite prepared in double distilled or ultra-purified water is oxidized with a solution of residual ozone and the excess nitrite ion is back-determined.

Range of application: 0-1 mg/L dissolved ozone

Precision and accuracy: detection limit 0.01 mg/L as ozone; accuracy: 0.005 mg/L

Interferences: the intercalibration method is applicable to pure solutions only

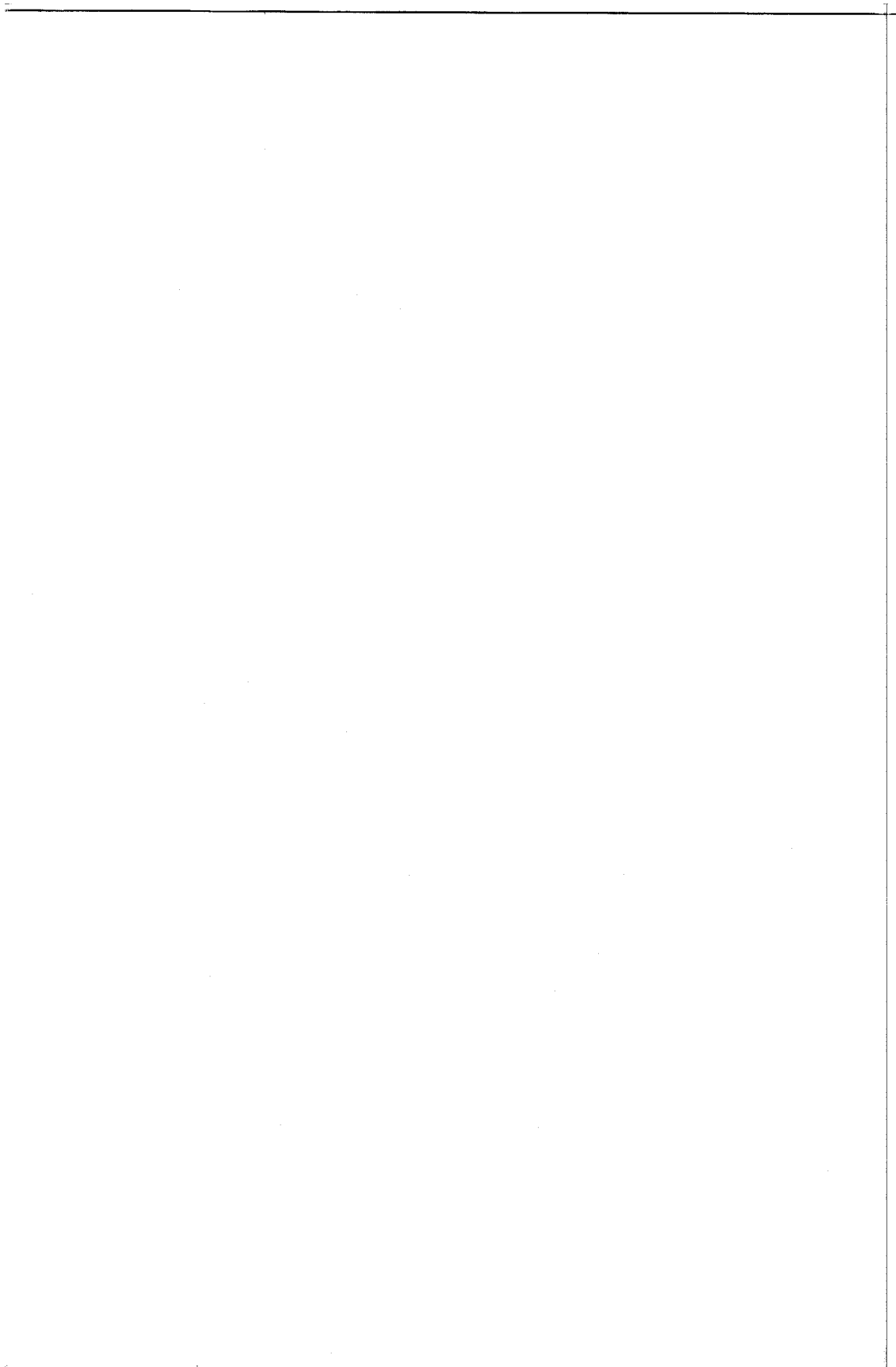
General conditions:

- Analytical grade sodium nitrite (e.g. Merck 6549, MM 69; or equivalent), is used to prepare a stock solution of 1g/L of nitrite ion. Immediately before use a probe of the stock solution is diluted ten times to obtain a working solution of 0.1 g/L in nitrite ion.
- Sulfanilic acid reagent for nitrite determination is prepared by dissolving 1 g sulfanilic acid (e.g. Baker Analyzed 1197 or equivalent) in 100 ml of a hot saturated solution of ammonium chloride in ultra-pure water. After cooling to room temperature mix with a solution of 1.5 g phenol (analytical grade) dissolved in 100 ml HCl, 2 molar.
- Concentrated analytical grade ammonium nitrate solution.
 - Pipette 10 ml of the working solution of 0.1 mg/L nitrite ion into a 1L volumetric flask and make up to 1L with the ozone solution under test. Residual nitrite concentration after reaction is measured spectrophotometrically.

Spectrophotometric determination: Take 50 ml of the solution after reaction, add 1ml of sulfanilic reagent and set aside for 15 minutes; then add 5 ml concentrated ammonia solution, mix and measure the absorbance at 435 nm to be compared versus a standardization curve.

REMARK. The method is applicable directly to solutions of ozone in water in concentrations up to 1mg/L. If higher aqueous ozone concentrations need to be monitored, the starting nitrite ion concentrations shall be adjusted accordingly.

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III. **COLORIMETRIC METHOD FOR MANUAL DETERMINATION OF OZONE CONCENTRATIONS IN WATER**

INTERNATIONAL OZONE ASSOCIATION Revised Guideline Document - 1998

A. *Water in Absence of Other Oxidants*

Principle: Potassium indigo-trisulfonate is discolored by aqueous ozone and the degree of discoloration is compared to a blank solution of the dye.

Range of application: 0.05 to 0.6 mg ozone per liter.

Range of performance characteristics: detection limit 0.06 mg/l; repeatability 0.02 mg/l (can be improved by a factor of 2 when thermostatic cells are used).

Interferences: Colorimetric methods in general are applicable to clear waters. This precise method is strictly applicable to waters containing ozone, in absence of other oxidants as aqueous chlorine, chloramines and related organo-chloramine oxidants, bromine or bromamines in water, hydrogen peroxide, manganese oxides.

Reagents:

Stock solution of indigo-trisulfonate made up from:

$C_{16}H_7N_2O_{11}S_3K_3$ (Molar Mass 616 f.e. Riedel de Haën AG-33317 or Aldrich Catalog No. 23.408-7) as a 1 mMol/l solution by dispersing the dye into a solution of analytical grade phosphoric acid at a concentration of 10^{-3} mol/l.

Optional Test: a 100-fold dilution of this solution has an optical density at 600 nm of 0.16 ± 0.01 and is gradually fading. The solution should be discarded if the absorption is lower than 80% of the starting value. Normally, the solution is stable for one month.

Working solution is made up immediately before use by dilution of 100 ml of the stock solution to 1L containing 10g of analytical grade NaH_2PO_4 and 7 ml of analytical grade H_3PO_4 .

Procedure:

Ten ml of working solution are introduced into each of two 100 ml volumetric flasks. One is filled with ozone-free water (e.g. distilled water) the other with the sample water by introducing the sample below the surface of the dye solution to prevent ozone loss by degassing.

Note: The pH-value of the diluted solutions must be lower than 4.

The difference in absorption of light at 600 nm between blank and sample is measured. The measurement is to be done as soon as possible but in all instances within 4 hours when stored in the dark.

Expression of results:

$$\text{mg/l (O}_3\text{)} = 1.11 \times \Delta \text{ absorption} / \text{Cell length (cm)} \times 0.42$$

(The proportionality constant is $(0.42 \pm 0.01) \text{ cm}^{-1}$ per mg/l ozone, which is equal to a difference in absorbance of 20,000 l/mol x cm).

Further reading: H. Bader & J. Hoigné, *Ozone Sci. & Eng.*, 4,169-178 (1982).

B. Water in which other oxidants (aqueous chlorine, chloramines, hydrogen peroxide, aqueous bromine, chlorite, chlorate, bromate) are potentially present at concentrations lower than 1 mg/l

Principle: Acid Chrome Violet K (also called Alizarin Violet 3R) of molar mass 622.25 (Color Index code No. 61710 ; in former editions No. 6170, e.g. Aldrich 22.783-8), is discolored by aqueous ozone and the degree of discoloration is compared to a blank solution of the dye.

Range of application: 0.06 to 0.6 mg ozone per liter,

Range of performance characteristics: detection limits 0.06 mg/l; repeatability 0.02 mg/l

Interferences: As for colorimetric methods, in general, this method is applicable to clear water.

The method is free of interference of other oxidants at concentrations possibly occurring in drinking water like aqueous chlorine, chloramines and related organo-chloramine oxidants) bromine or bromamines in water.

Reagents

1. A stock solution of ACVK is made up from Alizarin Violet 3R (Aldrich 22.783-8-CI code 61710, molecular mass 622.25) as a 0.2 mMol/l solution.
2. Disperse about 124.45 mg of the dye into an aliquot of 100-200 ml of pure water (ISO-3696; 1987 Grade 1) in a 1L volumetric flask. Mix magnetically overnight or by ultrasonic mixing during 10 min. at 20 kHz-60 Watt.
3. Add 20 mg of analytical grade sodium hexametaphosphate, followed by 48.5 g of analytical grade ammonium chloride and 1.6 g of ammonia expressed as NH_3 .
4. Dilute with water (ISO-3696; 1987 Grade 1), to 1L and stir for 8 hours.

Optional test: A 10-fold dilution of this solution has an absorbance of about 0.155 cm^{-1} . If lower than 0.130 cm^{-1} , a fresh stock solution of the reagent needs to be prepared.

Procedure

20 ml of the reagent solution are introduced in each of 200 ml volumetric flasks. One flask is filled with ozone-free water (e.g. distilled water), the other is filled with sample water by introducing the sample below the surface of the dye solution to prevent ozone loss by degassing. The molar ratio of Alizarin to ozone must be higher than 1.5.

The pH value of the diluted solutions must be between 8.1 and 8.5

The difference in absorption of light at 548 nm between blank and sample is measured. The measurement is so be done as soon as possible but in all instances within 30 min.

Expression of results:

$$\text{mg/l (O}_3\text{)} = \frac{\text{total volume (200 ml)} \times \Delta \text{ absorption}}{\text{Cell length (cm)} \times 0.059 \times \text{volume of sample (180 ml)}}$$

Further reading: W.J. Masschelein, G. Fransolet, P. Laforge & R. Savoir, *Ozone Sci. & Eng.*, **11**, 209-215 (1989).

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IV. OZONE CONCENTRATION MEASUREMENT AND MONITORING IN A CONCENTRATED PROCESS GAS BY UV-ABSORPTION

**INTERNATIONAL OZONE ASSOCIATION (EAG)
Revised Guideline Document - 1998**

Objective

The presently recommended procedure concerns the determination and monitoring of ozone by UV Absorption concentration in the range of 1-200g/m³ NTP in a dry process gas containing ozone in air, oxygen or mixtures of air and oxygen, containing or not other inert gases.

(NTP stands for Normal Temperature and Pressure reference conditions; i.e. 0° C; or 273.15 K and 1 Atm or 1.013x10⁵ Pa).

Background

The absorption of light between 200 and 300 nm by ozone (the Hartley band) can be used for the determination and monitoring of ozone concentration in the gas phase. The method is based on the Beer-Lambert absorption law which (in metric), is expressed in the form:

$$I = I_0 \times 10^{-ACd} \text{ or } \text{Log}(I_0/I) = ACd$$

Wherein I and I₀ are the measured UV intensities passing the absorption cell respectively with and without ozone present, C is the ozone concentration in mol/L; d the internal width of the absorption cell in cm and A the molar absorption index in L/mol x cm. At the maximum of the absorption band (260nm), the value of A is 3025 L/mol x cm. When using low-pressure mercury lamp sources emitting the 253.7 nm wavelength the A-value to be considered is 3000 +/- 30 L/mol x cm.; i.e. an instrumental accuracy of 1%. When using low pressure Hg lamps, light at wavelengths higher than 253.7nm shall be cut-off by appropriate filters and for light emitted at lower wavelengths, filters and/or specific diode detectors can be used. A monochromatism of +/- 2 nm shall be achieved.

Controlled electrical current feed to the lamps shall guarantee a constant light intensity output (I₀), even at fluctuations in the mains voltage.

Therefore the monitors shall be controlled by a build-in voltage stabilizer, which can compensate for possible fluctuations in voltage of the mains.

To obtain "NORMAL CONCENTRATION"; i.e. concentration at NTP, appropriate corrections for pressure and temperature shall be made:

$$C(\text{NTP}) = (\text{OD}/\text{Ad}) \times (P_{\text{NTP}}/P) \times (T/T_{\text{NTP}}).$$

(REMARK): Besides single and double beam technologies there exist on the market instruments including self-calibrating systems.

Calibration and Maintenance

Instrumental methods based on UV-absorption measurements shall be calibrated by wet-chemical determinations as by the iodometric methods (see EAG-Standard 1996). The recommended check-up of the instruments is either automatically or manually at least once a month for check of noise level observed with the process gas at zero ozone concentration. If the noise level exceeds 1% of the end-scale value, full diagnosis shall be made: cleanness of the cell(s), sensitivity of the photometric detector, age and emission yield of the light source; and, calibration of the instrument versus the wet chemical reference method shall be made.

Preventive full calibration and global maintenance shall be by periods not less than once every three months. Expected lifetime for reliable emission yield of the low pressure Hg-lamps is in the range of one year.

Procedure

- In case of doubt, the UV monitors shall be checked again at least, at two concentrations below 200 g/m³, NTP by the wet chemical potassium iodide reference method of IOA (version 1996).
- Only ozone resistant materials shall be used for transfer of sample gas: such as glass, quartz, PTEF, stainless steel 316, or higher grade.
- A minimum gas flow shall be established so that the overall delay between the sampling point and the exit of the measuring cell shall be less than one minute.
- Particular care shall be taken to avoid losses of gas in the transfer lines between sampling points and optical cell.
- In the single-beam type instruments, automatic checks of the zero value with ozone free gas shall be build-in in the automated system of monitoring. e.g. every 30 to 60 min.

Accuracy

The UV-absorption technique can be used at present in the concentration range up to 200 g/m³ (NTP) (see remark). An accuracy of 2% of the measured value can be attained. There is no interference from other molecules that may possibly be found in the output gas of ozone generators, like nitrogen oxides, hydrogen peroxide, nitric acid.

The cell path length shall be matched in function of the ozone concentration range.

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In automated read-out instruments (not analog, but digital or computerized), a label on the instrument shall indicate on which value of the molecular absorption index (A), the computation is based. Reference pressure and temperature at measurement shall be specified.

Remark

Beer's law is applicable at concentrations higher than 200 g/m³ NTP but difficulties exist for construction and operation with cells of very small path lengths. For higher concentrations, there will be a need for monitors operating at a different wavelength.

Safety

The off-gas after transit through the monitor shall not be directly discharged in the working rooms but shall be directed to the general off-gas system of the plant or treated catalytically on a coarse type catalyst. Pressure effects of these procedures shall be kept under control and integrated in the pressure correction of the measurement.

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***V. RECOMMENDED TERMS OF THE INTERNATIONAL OZONE
ASSOCIATION***

1998

IOA-EA3G.QAC

ACTIVE POWER	See POWER
ACVK METHOD	Method according to IOA standard 005/98 (F) for the determination of ozone in water. This colorimetric method uses the discoloration of a dye Alizarin Violet 3R by ozone.
ADSORPTION DRYER	See DRYER
ADVANCED OXIDATION PROCESS	Oxidation process which uses highly oxidative species resulting from one or several oxidative reactants introduced in the water. (Examples: photocatalytic process, combination ozone/UV, combination ozone/hydrogen peroxide, Fenton 's reagent, hydrogen peroxide/UV...)
AIR COOLED	See COOLING
AIR GAP	See DISCHARGE GAP

AIR PREPARATION SYSTEM or AIR CONDITIONING SYSTEM	<p>A system employed to dry and clean air before its introduction into the ozone generator when air is the gas used to produce ozone. The process consists of the following steps:</p> <ul style="list-style-type: none"> - removal of pollutants (in case of polluted air) - compression (inlet air compressor) - water cooling to condense water present in this air (heat exchanger and/or refrigerant drier) - removal of condensate - drying (on an adsorbent substance - desiccant drier or adsorption drier) - filtration (filters) <p>The main purpose of the air preparation system is to remove water of the feed gas (to lower the dew point).</p>
ALTERNATING CURRENT	See CURRENT
ALTERNATING VOLTAGE	See VOLTAGE
AMBIENT AIR	Generally refers to all space external to the gas flow of an ozonation process where the presence of ozone has to be avoided (working atmosphere, external part of ozone contactor or reactor, etc.)
AMBIENT AIR OZONE MONITOR	See OZONE MEASURING SYSTEM
Amp (A)	See AMPERE
AMPERE	<p>The unit used to measure intensity of an electric current. An ampere (A) is equal to the intensity of a constant current that, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed one meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} Newton per meter of length.</p> <p>A current of one ampere deposits 0,0011188 gram per second of silver from a solution of silver nitrate.</p>
AMPEROMETRIC METHOD	<p>Method according to IOA standard 003/89 (F) for the determination of ozone in water.</p> <p>This electrochemical method uses the reduction of ozone at a specific electrode. In some cases, it can be coupled with a membrane separation.</p>
ANALYSER	See OZONE MEASURING SYSTEM
ANNULAR SPACE	See DISCHARGE SPACE

Recommended Terms of the International Ozone Association 453

APPARENT CONTACT TIME	See CONTACT TIME
APPARENT POWER	See POWER
ATMOSPHERE	Generally refers to all space external to the gas flow of an ozonation process where the off-gas is vented (out of buildings)
AUTOMATIC OZONE PRODUCTION CONTROL	See CONTROL
BUBBLE SIZE	Generally refers to the diameter of the gas bubbles generated in a contact chamber by all means of gas diffusion in a liquid.
BUNSEN'S ABSORPTION COEFFICIENT	Bunsen's absorption coefficient indicates the volume of a gas dissolved per unit volume of the solvent at a determined temperature, if the partial pressure of the gas is 1 atmosphere.
CAPACITANCE	<p>The ratio of the instantaneous current through an ideal capacitor to the derivative with respect to time of voltage at its terminals. It is generally expressed in farad. One farad corresponds to the capacitance of a capacitor in which a voltage changing at the rate of one volt per second produces a current of one ampere.</p> <p>The "capacity" of a capacitor is its capacitance. It is proportional to the spacing of the two electrodes and depends on the electrical properties of the dielectric.</p>
CAPACITOR	A device consisting of two conducting plates separated from one another by an insulating material and used for storing electric charges.
CAPACITY	<p>DESIGN CAPACITY, NOMINAL CAPACITY : Production per hour of a given ozone generator or a group of ozone generators measured at specific conditions (concentration of ozone in the carrier gas, temperature of the coolant). Generally expressed in grams/hour or kilograms/hour.</p> <p>STANDBY CAPACITY : Reserve capacity not in operation when operating at design capacity.</p>
CARRIER GAS	The gas in which ozone has been generated and which carries the ozone to the reactor (or contactor).

CATALYTIC OZONE DESTRUCTOR	See DESTROYER
CEN	Comité Européen de Normalisation
CHARGE, ELECTRIC	A measure of the quantity of electricity. The electron is the elementary quantity of charge. The most widely used unit of charge is the Coulomb, which is a charge equal to $6.24 \cdot 10^{23}$ electron charges.
CHILLER	Consists of a chilling unit and a heat exchanger capable of cooling either a liquid (cooling water of ozone generators) or a gas (air from the air preparation system).
CO-CURRENT	See CURRENT (flow)
COLUMN	See CONTACT COLUMN
COMMON GROUND COMMON EARTH	See EARTH, GROUND
COMPONENTS	The equipment required to form a system for purposes of carrying out a process.
COMPRESSOR	<p>INLET (AIR OR GAS) COMPRESSOR</p> <p>A component of the gas preparation system. It is the compressor which compresses the feed gas to a required pressure.</p> <p>RECYCLE COMPRESSOR</p> <p>The compressor which recycles the gas to a required pressure for re-introduction to the process.</p>
CONCENTRATION	The amount of ozone per unit of volume. For dissolved ozone, the concentration is expressed in mg/l of water. For the ozone present in the gas, the concentration is expressed in mg O ₃ /l of gas in normal temperature and pressure conditions (0°C, 1 atm). Although it is improper, ozone gas concentrations can also be expressed in percent mass per mass or volume per volume.
CONDUCTOR	Any substance -usually a metal- which readily conducts electricity.

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CONTACT	<p>The action of applying ozone to a substance, whether solid, liquid or gaseous (OZONATION).</p> <p>CONTACT CHAMBER : OZONE CONTACTOR, OZONE REACTOR A vessel which contains one or several ozone contact zone.</p> <p>CONTACT COLUMN : A column where the mixing of the water to be ozonated with the ozone carrier gas occurs and where the chemical reactions between dissolved ozone and the components present in water are made possible.</p> <p>CONTACT COMPARTMENT : A part of the contact zone. Two types : diffusion compartment and reaction compartment.</p> <p>CONTACT ZONE : The contact zone is a combination of several contact compartments in series or in parallel in which ozone has a specific action (example: satisfying the ozone demand, disinfection...)</p> <p>DIFFUSION COMPARTMENT : Compartment where ozone is injected in the water to insure the transfer of ozone from the carrier gas to the flow of water and to ensure a part of reaction.</p> <p>OZONE CONTACTING SYSTEM : The part of the ozonation process where ozone gets in contact with the solid, liquid or gas to be treated. See CONTACTOR</p> <p>REACTION COMPARTMENT : Compartment in which ozone reacts with substrate dissolved in the water and in which no additional ozone is introduced.</p>
CONTACT TIME	<p>APPARENT CONTACT TIME, THEORETICAL HYDRAULIC DETENTION TIME, HYDRAULIC RESIDENCE TIME : In chemical engineering, this improper term corresponds to the theoretical hydraulic retention time of water in the reactor defined as the ratio between the volume of the reactor to the flow rate of the water.</p>

CONTACT TIME (CONT'D)	<p>HYDRAULIC DETENTION TIME : The real contact time takes the residence time distribution into account. An effective contact time is defined T_{10} (or T_5 for example). T_{10} (or T_5) corresponds to the amount of time it takes for ten percent (or five percent) of the water introduced at the contactor inlet to exit the contactor. The T_{10} (or T_5) is determined by the use of tracer studies. It means that 90 % (or 95 %) of the water remain in the contactor longer than the time corresponding to T_{10} (or T_5 respectively). See CT_{10} CONCEPT.</p> <p>CONTACT TIME (T_{10}) : Time necessary for 10% of tracer injected to be recovered at the outlet; depends on the hydrodynamics of the reactor and is always smaller than the hydraulic residence time (V/Q), except in the case of perfect plug flow. For example, T_5 (or other) are defined as T_{10}.</p>
CONTACTOR	See CONTACT. Term mainly used in the chemical industry. Use preferentially the term REACTOR.
CONTROL	<p>CONTROL PANEL : The control panel which makes up part of measurement and control system.</p> <p>OZONE PRODUCTION CONTROL : The method whereby the amount of ozone being produced by an ozone generator or a group of ozone generators is regulated.</p> <p>MANUAL OZONE PRODUCTION CONTROL : A method of controlling the quantity of ozone produced by one or several ozone generators by operator intervention.</p> <p>AUTOMATIC OZONE PRODUCTION CONTROL : A method of controlling the quantity of ozone produced by one or several ozone generators from set point values and information given by the ozonation process without the intervention of an operator. The signal can arrive e.g. from the measurement of the volumetric rate of water flow, the residual ozone concentration or any external measurements of chemical parameters.</p> <p>MEASUREMENT AND CONTROL SYSTEM : A part of the ozonation process which groups all instruments and controls.</p>

CONTROL (CONT'D)	<p>FEEDBACK SYSTEM : A method of controlling a process taking into account signals from one or several indicators placed downstream of the process. For example, the ozone generation can be controlled to maintain a required dissolved ozone residual measured at the outlet of the reactor or contact chamber.</p> <p>FEEDFORWARD SYSTEM: A method of controlling a process taking into account signals upstream of the process. For example, the ozone generation can be controlled to a measure of the water-to-be-treated flow rate and to a set-point treatment rate. <u>Remark:</u> a process can be controlled by means of several control loops requiring either a feedforward or a feedback control.</p>
COOLER	See CHILLER
COOLING	<p>COOLING SYSTEM : This refers to the components used to cool the feed gas, the ozone generator and the power supply equipment.</p> <p>COOLING AIR : The term applied to the air which is used as a cooling media in the ozone generators or power supply system.</p> <p>COOLING WATER : The term applied to the water which is used as a cooling media in the ozone generators or power supply system.</p>
COOLING (CONT'D)	<p>AIR COOLED : This term refers to the manner in which heat produced during the generation of ozone is removed from the ozone generator or the power supply system. An ozone generator is air cooled if air is the source of cooling.</p> <p>DOUBLE COOLED, DUAL COOLED : Generally refers to a class of ozone generator in which the cooling system is made up of two cooling circuits: one to cool the high voltage electrode and the other to cool the low voltage electrode.</p> <p>WATER COOLED : In an OZONE GENERATOR or a power supply system when the media for cooling is solely water, the unit is said to be water cooled.</p>
CORONA DISCHARGE	See DISCHARGE
COUNTER CURRENT	See CURRENT (flow)

CT ₁₀ CONCEPT	USEPA criterion (based on Chick Watson 's law) disinfection efficiency estimation; product of the residual disinfectant concentration C and contact time T ₁₀ determined by tracer studies or numerical simulation for a given reactor. See CONTACT TIME (T ₁₀)
CURRENT (electrical)	<p>The electrical current (symbol I) is the directed motion of free electrons in an electrical conductor. The electrical current is measured in A.</p> <p>ALTERNATING CURRENT (A.C.) : A periodic current the average value of which is zero.</p> <p>DIRECT CURRENT : A DIRECT CURRENT is one which retains the same polarity, as opposed to A.C.</p> <p>EFFECTIVE CURRENT : Root-mean-square value of the alternating current intensity. The effective value of an electrical alternating current is the permanent value resulting from the sine curve, generating in an electrical resistance the same heat as a direct current having the same current intensity. Root-mean-square value of the alternating current intensity.</p>
CURRENT (flow)	<p>CO-CURRENT : A term used to describe the flow of fluids in a reactor where the water to be treated and the ozone carrier gas flow are in the same direction.</p> <p>COUNTER CURRENT : A term used to describe the flow of fluids in a reactor where the water to be treated and the ozone carrier gas flow are in the opposite direction (generally gas-upflow, liquid down flow).</p> <p>CROSS CURRENT : A term used to describe the flow of fluids in a reactor where the water to be treated and the ozone carrier gas flow are at 90° to each other (ozone carrier gas upflow).</p>
DEHUMIDIFIER	See MOISTURE SEPARATOR, DRIER
DEMISTER	A component designed to remove liquid droplets from a gas stream.
DE-OZONIZE	A term used to describe an action designed to remove ozone from a solid, liquid, or gas.
DESICCANT	See DRIER.

DESICCATOR	See DRIER
DESICCANT DRIER	See DRIER
DESIGN CAPACITY	See CAPACITY
DESTRUCTOR	<p>OZONE DESTRUCTION UNIT : Normally a component of the off gas treatment system it is one, or a number of items which in combination will destroy some or all of the ozone present in the off-gas being vented from the reactor. A component designed to destroy the ozone present in a gas.</p> <p>CATALYTIC OZONE DESTRUCTOR : A class of ozone destruction unit that uses a catalyst.</p> <p>THERMAL OZONE DESTRUCTOR : An ozone destruction unit that uses high temperature.</p>
DEW POINT	<p>The theoretical temperature to which a gas must be cooled and at which, for a given pressure (i.e. 1 atmosphere), the vapor contained in this gas begins to condense. The dew point is measured after the desiccant driers in order to check the air moisture content before entering the ozone generators. According to the actual state of technique, an atmospheric dew point of -60°C has to be aimed at for the feed gas of an ozone generator to extend the life of the ozone generation elements, to increase the ozone production and to reduce the formation of nitrogen oxide.</p>
DIELECTRIC	<p>DIELECTRIC : The dielectric consists of non-conductive insulating materials between the plates of the capacitor and prevents charge equalization between the electrodes inside the capacitor. If an ozone generator is concerned, the dielectric between the electrodes consists of gas and glass or of gas and any insulating materials.</p> <p>DIELECTRIC CONSTANT : The ratio between capacitance of two identical capacitors except that for one the dielectric is air. The dielectric constant is also known as the dielectric coefficient, specific inductive capacitance or relative permittivity.</p> <p>DIELECTRIC FLUID : An insulating coolant media found in some transformers. In general, this liquid is oil</p>

DIELECTRIC (CONT'D)	<p>DIELECTRIC OIL : A specific type of a dielectric liquid contained in a liquid filled transformer.</p> <p>DIELECTRIC PLATE : A dielectric in plate form.</p> <p>DIELECTRIC TUBE, TUBULAR DIELECTRIC : A dielectric in tubular form.</p>
DIFFUSER	<p>A component of the ozone contacting system found in a reactor which allows diffusion of the ozone containing system with fine bubbles. (Types of bubble diffuser system : Tubular-type diffuser, dome or disc-type diffuser)</p>
DIFFUSION	<p>Migration of dissolved molecules in a medium liquid. In a technical terminology, diffusion is also used for contacting of ozone gas with a liquid.</p> <p>DIFFUSION COMPARTMENT : See CONTACT</p> <p>DIFFUSION GRID : A collection of diffusers grouped together in one reactor or in one contact compartment.</p>
DILUTION	<p>A method of reducing the concentration of ozone in the gas or liquid by adding a volume of another gas or liquid.</p>
DIRECT CURRENT	See CURRENT
DIRECT VOLTAGE	See VOLTAGE
DISCHARGE	<p>DISCHARGE GAP, DISCHARGE SPACE, AIR GAP, GAP : The gas space between the dielectric and electrode in an ozone generator across which a potential difference is applied and in which the corona discharge occurs.</p> <p>ANNULAR SPACE : The discharge space in an ozone generator using tubular dielectrics or dielectrics tubes..</p> <p>CORONA DISCHARGE, BARRIER DISCHARGE : Glow production in a non-uniform and high electrical field, the faint glow apparent adjacent to the dielectrics in an ozone generator during ozone production.</p>

DISCHARGE (CONT'D)	<p>DISCHARGE SURFACE : A discharge surface is the active electrode surface.</p> <p>GLOW DISCHARGE : Gaseous and autonomous conduction ensured by charge carrier, which are mostly electrons produced by a secondary electronic emission. Term used improperly for the generation of ozone.</p> <p>HIGH VOLTAGE DISCHARGE : Generally the name given to the electrical discharge across the discharge space.</p>
DISSOLVED OZONE RESIDUAL	See RESIDUAL OZONE
DISSOLVED OZONE MONITOR	See OZONE MEASURING INSTRUMENT
DISTRIBUTOR	A system allowing for the distribution of a fluid.
DOSE	<p>APPLIED OZONE DOSE (RATE), INJECTED OZONE DOSE (RATE), INTRODUCED OZONE DOSE (RATE), TREATMENT DOSE (RATE) : Mass of ozone introduced, injected or applied to a contacting system is equal to the mass of transferred ozone plus the mass of ozone present in the off-gas) per unit of mass or volume of substrate or liquid treated. The mass of a substance (ozone) applied to a unit volume or quantity of liquid (or solid) generally expressed in milligram per liter or gram per cubic meter.</p> <p>CONSUMED OZONE DOSE, RATE : (Mass of ozone introduced, injected or applied in a contacting system, minus mass of ozone present in the off-gas minus mass of ozone present in the liquid or solid ; generally expressed in milligram per liter or gram per cubic meter.</p> <p>TRANSFERRED OZONE DOSE, RATE : (Mass of ozone introduced, injected or applied in a contacting system minus mass of ozone present in the off-gas. It is equal to (the mass of ozone consumed plus the mass of residual ozone dissolved) per unit of mass or volume of substrate or liquid treated ; generally expressed in milligram per liter or gram per cubic meter.</p>
DOUBLE COOLED	See COOLING

DRIER	<p>DESICCANT DRIER, REFRIGERANT DRIER, ADSORPTION DRIER, MOISTURE SEPARATOR</p> <p>DESICCANT : The water vapor adsorptive material found inside a desiccant dryer.</p> <p>ADSORPTION DRIER, DESICCANT DRIER : A component of the air preparation system whose purpose is to retain on a desiccant the water vapor contained in the gas.</p>
DRIER (CONT'D)	<p>RECYCLE DRIER : A drier for the recycle gas.</p> <p>REFRIGERANT DRIER : A component of the gas preparation system which uses A refrigeration process to reduce the water vapor.</p> <p>MOISTURE SEPARATOR : A component of the air preparation system whose purpose is to reduce the amount of water vapor present in a gas.</p>
DUAL COOLED	See COOLING
EARTH	See GROUND
EARTH CONDUCTOR	See GROUND
EARTH ELECTRODE	See ELECTRODE
EDUCTOR (UK)	See INJECTOR (US)
EFFECTIVE CURRENT	See CURRENT
EFFECTIVE VOLTAGE	See VOLTAGE
EFFICIENCY	A measure of the performance of a unit system or PROCESS. For example, mass transfer efficiency, chemical reaction efficiency, electrical efficiency.
ELECTRICAL FREQUENCY	See FREQUENCY
ELECTRICAL POTENTIAL	See POTENTIAL
ELECTRICAL POWER	See POWER

ELECTRODE	<p>GROUND ELECTRODE, EARTH ELECTRODE : Generally refers to the electrode in an ozone generator which is connected to ground (see low voltage electrode or earth voltage electrode).</p> <p>HIGH VOLTAGE ELECTRODE : This refers to an element in the ozone generator connected to the secondary (high voltage) of the high voltage transformer, which generally is at a voltage greater than 1000 volts. It also refers to the terminal point inside an ozone generator which is the inlet terminal for the electrical power. This high voltage electrode is generally be covered by a dielectric material at high voltage as opposed to a low voltage electrode or a ground electrode.</p> <p>LOW VOLTAGE ELECTRODE or EARTH VOLTAGE ELECTRODE: Refers to the electrode surface inside and ozone generator which is connected to the common ground terminal.</p>
EMULSIFIER	Term used in ozone practice for bringing into contact ozone containing gas with a liquid through an injector and a dissolution device.
ENERGY	Physical measurement typical of a system expressing its capacity to alter the condition of other systems through work. Energy cannot be destroyed but only transformed into other modes of energy. The unit of energy is the joule. One joule is the work done by a force of one newton acting through a distance of one meter in the direction of the force.
EXCHANGE POTENTIAL DIFFERENCE	See MASS TRANSFER
EXTERNAL LOOP	See LOOP
FEEDBACK SYSTEM	See CONTROL
FEEDFORWARD SYSTEM	See CONTROL
FEED GAS	The gas which feeds the ozone generator.
FEED GAS PREPARATION SYSTEM	<p>A system employed to prepare the gas before its introduction into the ozone generator. When air is the gas used to produce ozone (see AIR PREPARATION SYSTEM);</p> <p>When oxygen is the feed gas it could be prepared by several ways: Liquid oxygen, VSA, PSA, VPSA, MPSA, PVSA.</p>

FILTER	A component for the removal of suspended substances from a fluid stream.
FLOW CONTROL	A system for controlling the quantity of gas or liquid flowing through a system
FREQUENCY (electrical)	<p>ELECTRICAL FREQUENCY : The number of periods of the alternating current per unit time. The unit of frequency is the hertz (Hz). One hertz is the frequency of a periodic phenomenon whose period is one second.</p> <p>HIGH FREQUENCY : The term of a determined range of electrical frequency. High frequencies are frequencies equal to or greater than 100 kHz.</p> <p>LINE FREQUENCY, STANDARD FREQUENCY or MAIN FREQUENCY: Refers to the electrical frequency of the line (mains) which usually is 50 or 60 Hertz.</p> <p>LOW FREQUENCY : The term of a determined range of electrical frequency. Generally low frequency is synonymous with line frequency and is 50 or 60 Hz.</p> <p>MEDIUM FREQUENCY : Generally refers to the operating frequency of an ozone generator. Medium frequency ranges than 60 up to 100 kHz.</p>
GAP, GAP DISCHARGE	See DISCHARGE SPACE
GAS	A physical state of a substance depending on pressure and temperature in which it can expand indefinitely and completely fill its container.
GAS COMPOSITION	An inventory of the constituents of a gas expressing their concentrations in the gas at normal conditions of temperature and pressure (O°C, 1 atm).
GAS HOLD-UP	See HOLD-UP
GAS PREPARATION SYSTEM	See FEED GAS PREPARATION SYSTEM
GAS PRESSURE	See PRESSURE

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GAS TEMPERATURE	See TEMPERATURE
GLOW DISCHARGE	See DISCHARGE
G.O.T. (GAS OZONE TEST)	See OZONE WATER DEMAND TEST
GROUND	<p>In the electrical sense, a large conducting body (such as the earth) used as a common return for an electric circuit and an arbitrary zero of potential. Ground also refers to an object or conductor that makes an electrical connection with the earth by negligible impedance.</p> <p>COMMON GROUND, COMMON EARTH A conductor common to all electric devices connected to the earth by a negligible impedance. Strictly speaking it is the grounded neutral point on the transformer of the power generator of the energy supplier. In case of the ozone generation it is the electrical distribution point to which each electrically conductive housing section of the total plant is connected. The common ground has also to be connected to the operating ground/or foundation ground.</p> <p>LINE GROUND, EARTH CONDUCTOR : The ground of the line.</p> <p>SYSTEM GROUND, EARTH CONNECTION SYSTEM : The ground for a system.</p>
GROUND ELECTRODE	See ELECTRODE
GROUND STATE	The energy level having the least energy of all possible states.
GROUND LEVEL	See GROUND STATE
HEAT EXCHANGER	A component capable of transferring heat from one medium to another medium.
HENRY's LAW HENRY's COEFFICIENT	<p>For a gas as ozone, the law that in equilibrium conditions the partial pressure of ozone in the gas phase is proportional to the concentration of ozone in the liquid (applicable for low concentration of ozone).</p> <p>The factor of proportionality is Henry's coefficient depending on temperature, pH. The gas solubility increases with decreasing operating temperature and increasing working pressure.</p>

HIGH CONCENTRATION OZONE MONITOR	See OZONE MEASURING INSTRUMENT
HIGH FREQUENCY	See FREQUENCY
HIGH TENSION	See TENSION
HIGH VOLTAGE	See VOLTAGE
HIGH VOLTAGE DISCHARGE	See DISCHARGE
HIGH VOLTAGE ELECTRODE	See ELECTRODE
HOLD UP	GAS HOLD UP : The ratio of the gas volume contained in the liquid phase to the total volume of the liquid phase (gas volume plus liquid volume).
HYDRAULIC DETENTION TIME	See CONTACT TIME
HYDRAULIC RESIDENCE TIME	See CONTACT TIME
INDIGO METHOD	Method according to IOA standard 004/89 and 006/89 for the determination of residual ozone and traces of ozone in water. This colorimetric method uses the highly selective discoloration of a dye (indigo trisulfonic acid) by ozone.
INDUCTANCE	The ratio of instantaneous voltage at the terminals of an ideal inductor and the derivative with respect to time, of the current crossing it, measured in Henry.
INDUCTOR	A physical device, generally a coil, which opposes a fast change of the electrical current passing it. VARIABLE INDUCTOR : A two-terminal circuit whose inductance can be modulated.
INJECTOR	A device in which a motive fluid is used as a jet stream to induct another fluid and to mix them together.
INLET COMPRESSOR	See COMPRESSOR
INSTALLED POWER	See POWER.

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INSTANTANEOUS POWER	See POWER
INTERMEDIATE OZONATION	Refers to ozonation between clarification and filtration or between 2 filtration stages.
INTERNAL LOOP	See LOOP
INVERTER (frequency)	A machine or device for changing one frequency to another.
IODOMETRIC METHOD	Method according to IOA standard 001/95 for the determination of ozone in a process gas. This volumetric method uses the oxidation of iodide to iodine using ozone, then the titration of produced iodine by a thiosulfate solution.
ISO	International Standardization Organization
LINE FREQUENCY	See FREQUENCY
LINE GROUND	See GROUND
LINE VOLTAGE	See VOLTAGE
LIQUID	A physical state of substance depending on pressure and temperature.
LONG LOOP	See LOOP
LOOP	<p>SHORT LOOP, INTERNAL LOOP : Process installed after an ozone generator or a group of ozone generators and before the contacting system, allowing the recycling of oxygen for ozone generation.</p> <p>The oxygen and the ozone are separated directly down-stream of the ozone generator. The ozone is then transported by a carrier gas into the process at the same or a higher concentration than it was generated. This carrier gas may be nitrogen, air or any other gas that is readily available and compatible with the separation technology that is used.</p> <p>LONG LOOP, EXTERNAL LOOP : Process installed after an ozone contacting system (contactor) allowing the recycling of oxygen (the carrier gas) for ozone generation by removal of contaminants and moisture content in a series of unit operations.</p>
LOW CONCENTRATION OZONE MONITOR	See OZONE MEASURING INSTRUMENT

LOW FREQUENCY	See FREQUENCY
LOW TENSION	See TENSION
LOW VOLTAGE	See VOLTAGE
LOW VOLTAGE ELECTRODE	See ELECTRODE
MAINS SUPPLY	Usually refers to the plant power supply made available for the ozonation process.
MAINS	See LINE, MAINS
MAKE-UP GAS	The name given to the type and quantity of gas to bring the recycling gas up to the correct flow volume and purity at ozone generator inlet.
MANIFOLD	A piping SYSTEM which enables distribution of a fluid.
MANUAL OZONE PRODUCTION CONTROL	See CONTROL
MASS TRANSFER COEFFICIENT	<p>OVERALL MASS TRANSFER COEFFICIENT ($k_L \cdot a$) (s^{-1}): This parameter characterizes the transfer from a gas (ozone) to a liquid. Product of the mass transfer coefficient (k_L) and the specific exchange area (a).</p> <p>MASS TRANSFER COEFFICIENT (k_L) ($m \cdot s^{-1}$): This parameter characterizes the speed of diffusion from a gas (ozone) to a liquid.</p> <p>DRIVING FORCE OF TRANSFER ; MASS TRANSFER POTENTIAL : Difference between the ozone concentration (in the liquid phase) at the interface gas liquid (related to Henry law) and the ozone concentration in the liquid phase. The parameter represents the driving force of transfer.</p>
MATERIALS OF CONSTRUCTION	The materials from which the components are fabricated.
MEASUREMENT AND CONTROL SYSTEM	<p>See CONTROL, MONITORING</p> <p>A part of the ozonation process that groups all instruments and controls.</p>

MEDICAL-USE OZONE	OZONE applied for therapeutic purposes in human or veterinary medical treatment.
MEDIUM FREQUENCY	See FREQUENCY.
MOISTURE CONTENT	Generally refers to the amount of water vapor contained in a given gas. It is characterized by the dew point.
MOISTURE SEPARATOR	See DRYER
NITRITE CALIBRATION METHOD	Method according to IOA standard 003/89 (F) for the calibration of analytical methods applicable for the determination of ozone in water. This method uses the oxidation of nitrite to nitrate by ozone and the dosage of nitrite by a spectrophotometric method.
MONITOR	See OZONE MONITOR.
NOMINAL CAPACITY	See CAPACITY
NORMAL CONDITIONS OF TEMPERATURE AND PRESSURE	Reference conditions for expressing a gas volume at a temperature of 0°C or 273.15 K and a pressure : 1.013 10 ⁵ Pa or 1 atm Expressed in m ³ NTP, l NTP, m ³ _n , l _n .
NORMS	See STANDARDS
OFF-GAS	The gas which is vented to ATMOSPHERE from the reactor or from an ozone destructor.
OFF-GAS TREATMENT SYSTEM	A group of components which form a part of the ozonation process. Their purpose is to eliminate or diminish the ozone concentration in the off-gas to acceptable levels.
OHM	Unit of measure of the electrical resistance. Symbol A resistance of one ohm is the electric resistance between two points of a passive circuit carrying a constant current of one ampere when there is a potential difference of one volt between both points.
OPERATING VOLTAGE	See VOLTAGE
OPERATOR	The person who is operating the process.

OSWALD'S ABSORPTION COEFFICIENT	Oswald's absorption coefficient means the ratio of the ozone concentration of the gas composition in the equilibrating liquid phase and the ozone concentration in the gas phase. It does not depend on the absolute pressure but on the temperature of the liquid.
OVERALL MASS TRANSFER COEFFICIENT	See MASS TRANSFER COEFFICIENT
OXYGEN ENRICHED GAS	A gas which previously contained oxygen and to which more oxygen has been added.
OXYGEN RECYCLE	Refers to the re-use of the oxygen into a feed gas that has once passed through an ozone generator or an ozonation process. Remark: on a wastewater treatment plant, the oxygen off-gas could be recycled into the activated sludge basin.
OZONATE	To induce the chemical process where ozone reacts with other reagents of solid, liquid or gas thereby producing new compounds. Term used today for the act of bringing ozone into contact with a solid, liquid or gas.
OZONATION	The process whereby a compound reacts chemically with OZONE and in which the compound is itself chemically changed. Term used today for the act of bringing ozone into contact with a solid, liquid or gas.
OZONATION PROCESS	A sequence of steps, in which ozone is generated, brought into contact with a solid, liquid or gas, and in which one or more constituents of the medium or substance react chemically with ozone.
OZONE	The triatomic form of oxygen having the chemical symbol O_3 and a molecular weight of 47.9982 g.
OZONE ABSORPTION	See SOLUBILITY
OZONE APPLIED	See TREATMENT DOSE
OZONE CHARGE	Term used improperly in pulp and paper industry instead of ozone applied e.g. kg O_3 /ton of pulp.
OZONE CONCENTRATION	See CONCENTRATION

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OZONE CONSUMED, OZONE CONSUMPTION	(Mass of ozone transferred in a contacting system minus mass of residual ozone dissolved) per unit of mass or volume of substrate treated.
OZONE CONTACTOR	See CONTACT
OZONE CONTACTING SYSTEM	See CONTACT
OZONE-CONTAINING FLUID	A gas or liquid which contains ozone.
OZONE DECOMPOSITION	See OZONE HALF-TIME
OZONE DEMAND	See OZONE WATER DEMAND TEST
OZONE DESTRUCTION UNIT	See DESTRUCTOR
OZONE ENRICHED GAS	A gas which previously contained ozone and to which more ozone has been added.
OZONE GENERATION	Ozone is generated when applying a silent electrical discharge to oxygen-containing gases. The electrical discharge occurs in most up-to-date ozone generators in a gas space between electrodes put under high voltage which are separated by a dielectric. The formation of ozone from over atomic radical oxygen recombined with molecular oxygen to form ozone.
OZONE GENERATION ELEMENT	A device in which gases containing oxygen are exposed to a silent electrical discharge.
OZONE GENERATOR	A device in which the ozone generation elements and the whole equipment required for the production of ozone are incorporated (for compact ozone generator).
OZONE GENERATING SYSTEM	A system for ozone generation. A group of devices comprising the ozone generator and the electrical power supply equipment.
OZONE HALF-LIFE	Time required for 50% of a given quantity of ozone, either in gas or liquid phase, to decompose under specific conditions (temperature, pressure, pH, etc.).
OZONE HOLE	A zone in the atmosphere of the earth in which the ozonosphere has been destroyed by environmental influences.

OZONE INTRODUCED, INJECTED	See TREATMENT DOSE
OZONE LAYER	See OZONOSPHERE
OZONE MASS TRANSFER YIELD	See TRANSFER YIELD
OZONE MEASURING INSTRUMENT	<p>A device which measures the amount or concentration of ozone present in a given sample of liquid or gas in a continuous or intermittent (sequential) manner.</p> <p>AMBIENT AIR OZONE MONITOR, AMBIENT AIR OZONE MEASURING INSTRUMENT : An ozone measuring instrument to measure concentrations in the ambient air or in atmosphere to make sure that the maximum acceptable value (0,1 ppmv - 0.2 mg/m³) in a working atmosphere is not exceeded or to make sure that ozone destructors work properly.</p> <p>DISSOLVED OZONE MONITOR, DISSOLVED OZONE MEASURING INSTRUMENT : An ozone measuring instrument which can make up part of an ozone production control system and which continuously or intermittently measures the dissolved ozone concentration in a liquid.</p> <p>HIGH OZONE CONCENTRATION OZONE MONITOR, HIGH OZONE CONCENTRATION OZONE MEASURING INSTRUMENT : An instrument that measures continuously or intermittently the ozone concentration in the gas at the ozone generator outlet or at the ozonation reactor outlet. Such an analyzer can be part of an ozone production measuring control system (from 10 to 200 g/m³ NTP).</p> <p>LOW CONCENTRATION OZONE MONITOR, LOW CONCENTRATION OZONE MEASURING INSTRUMENT : An ozone measuring instrument capable of measuring continuously or intermittently low concentrations of ozone gas. A concentration is said to be low when it is lower than 100 ppm by volume or 214 mg/m³ NTP.</p>
OZONE MONITOR	See OZONE MEASURING INSTRUMENT
OZONE PRODUCTION	See PRODUCTION RATE
OZONE PRODUCTION CONTROL	See CONTROL

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OZONE-RESISTANT	Any material which is not subject to decomposition or deterioration when in the presence of ozone.
OZONE SOLUBILITY	See SOLUBILITY
OZONE WATER DEMAND TEST	<p>Tests developed for the design of an ozonation system, to determine the dosage of ozone to apply to treat water under predetermined conditions, or to maintain a residual during a certain period of time.</p> <p>Two tests are usual :</p> <ul style="list-style-type: none"> - the solution ozone test (S.O.T) : injection of a dissolved ozone containing solution into water to be treated - the gaseous ozone test (G.O.T.) : injection of a ozone containing gas into the water to be treated, also called OZOTEST. <p>These tests determine the initial ozone demand or initial ozone consumption and the half time value.</p>
OZONIDE	An intermediate product of the ozone reaction with alkenes. Cyclic peroxidic derivative (trioxalanes 1,2,4) obtained during ozonation of compounds with unsaturated carbon-carbon bonds. Compound generally unstable and hydrolyzed in water.
OZONIZATION	See OZONATION.
OZONIZE	See OZONATE
OZONIZED GAS	A gas which has passed through an ozone generator.
OZONIZED (or OZONATED) LIQUID	A liquid which has passed through an ozone reactor and which has been mixed with an ozone carrier gas.
OZONIZED (or OZONATED) SOLID	A solid which has passed through an ozone reactor and which has been mixed with an ozone carrier gas.
OZONIZER	See OZONE GENERATOR
OZONOLYSIS	The use of ozone to locate double bonds of alkenes to form ozonide.
OZONOSPHERE	An atmospheric layer at heights of 15 to 40 kilometers where much of the atmospheric ozone (O ₃) is concentrated. It is characterized by high absorption of ultraviolet solar radiation.
OZOTEST	See OZONE WATER DEMAND TEST

POST OZONATION	Refers to ozonation at the end of a water treatment process, generally after filtration.
POTENTIAL	<p>Scalar potential of the electric field</p> <p>ELECTRICAL POTENTIAL The electrical potential of a point is the potential difference between that point and a point at infinity. It is the scalar potential of an electric field.</p> <p>POTENTIAL DIFFERENCE : The difference of electric potentials V_a and V_b between any two points of an irrotational electric field, equal to the voltage, independent of the path between the two points.</p>
POWER	<p>ACTIVE POWER : The active power is the power really absorbed from the mains of an ozone generator and permanently transformed into another form of energy. It is calculated as mean value of the time-depending power through a period or as product of the apparent power with the power factor. The unit is W or kW.</p> <p>APPARENT POWER : This is the product of effective voltage and effective current between two points of an electric circuit expressed in VA or kVA. The apparent power is the power absorbed by the ozone generator and is the product of the effective values of current and voltage.</p> <p>EFFECTIVE POWER : The square root of the average of the square of the instantaneous values of the power taken throughout one period. (See ACTIVE POWER)</p> <p>INSTALLED POWER : The product of effective voltage and current (maximum). The arithmetic sum of all of the active power if all of the components in the ozonation process are operating at the same time at their nominal capacity.</p>

POWER (CONT'D)	<p>INSTANTANEOUS POWER : The product of instantaneous voltage and current measured between two points of an electric circuit such as an access.</p> <p>POWER FACTOR : The ratio of the active power (watt) to the apparent power (VA) (equal to the cosine of the phase angle between the voltage and the current when the voltage is sinusoidal). It is often referred to as $\cos \phi$ which represents the variance from zero of the phase angle ϕ if sine-shaped figures are concerned. The phase shifting of current and voltage can be positive or negative, according as the circuit is capacitive or inductive in nature. The range of power factor is from power factor 1 which represents resistance only, to zero which represents reactance only.</p> <p>REACTIVE POWER : Reactive power is always generated if electrical impedance is existing in an alternating circuit which are not purely of an ohmic nature which is generally the case in practice. Inductive and capacitive portions of electrical impedance become effective as reactance and result in a positive or negative phase shifting between current and voltage resulting, in reactive power. The dimension of the reactive power is Var.</p> <p>SPECIFIC POWER CONSUMPTION : The specific power consumption is the active power (measured at the input of the frequency converter i.e. at the mains) required to produce one kilogram per hour of ozone at a determined ozone concentration and cooling water temperature. Generally, the specific power consumption is given as kilowatt-hour per kilogram of ozone on a daily basis.</p>
POWER SUPPLY UNIT (PSU)	The PSU groups all the electrical components which transform and modulate voltage, current and frequency to supply electrical power to an ozone generator.
PRE-OZONATION	Refers to ozonation at the beginning of a water treatment process, generally before clarification.
PRESSURE (gas)	The force exerted by a gas on the surface of its container. The unit of pressure is the Pascal (Pa). One Pascal corresponds to the pressure resulting from a force of one newton acting uniformly over and at right angles to an area of one square meter.
PROCESS	A systematic series of actions directed to some end. A series of treatment stages to achieve a specific result.
PROCESS GAS	See CARRIER GAS
PRODUCTION CONTROL	See CONTROL

PRODUCTION RATE (continuous)	The production of an ozone generator measured over a long period. The rate is expressed in kilograms per hour or in grams per hour at a determined ozone concentration, cooling water temperature and gas pressure.
PSA PRESSURE SWING ADSORPTION	Process used to separate air components (principally nitrogen and oxygen) by selective adsorption on an adsorbent such as a molecular sieve (like zeolite) that takes place at a pressure above atmosphere. The regeneration phase or desorption is carried out by decreasing the pressure down to atmospheric pressure.
PURGE	The act of removing or reducing the concentration of one or several gas compounds, in the recycle loop of the carrier gas, or on a desiccant drier.
REACTANCE	Reactance is the inductive portion of the total electrical impedance in an electrical impedance when using electrical alternating current.
REACTION COMPARTMENT	See CONTACT
REACTION RATE	Refers to the rate at which a given reaction with OZONE occurs.
REACTION VESSEL	See CONTACTOR
REACTOR	See CONTACTOR
REACTOR (electrical)	See INDUCTOR
REACTIVE CIRCUIT	A circuit containing inductance or capacitance.
REACTIVE POWER	See POWER
RECTIFIER	A device for converting an alternating current (ac) to a direct current (dc).
RECYCLE COMPRESSOR	See COMPRESSOR
RECYCLE DRYER	See DRYER
RECYCLE GAS	A gas used more than once either for ozone generation or ozonation.

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RECYCLE GAS TREATMENT SYSTEM	A part of an ozonation process whose purpose is to treat the gas from the ozone contactor in order to recycling it to the ozone generator.
REFRIGERANT DRYER	See DRYER
REMOTE OPERATION	Remote-controlled operation refers to the control of an ozone generator or an ozonation process at a distance from the plant site.
RESIDUAL	See RESIDUAL OZONE
RESIDUAL OZONE	Generally refers to the amount of ozone found in a sample (gas or liquid) after contact and reaction. DISSOLVED OZONE RESIDUAL : The concentration of dissolved ozone measured in a liquid at a specific point of an ozonation process.
RESISTANCE	The quotient of the voltage at the terminals of an ideal resistance to the current passing through it. The real part of complex impedance.
RETENTION TIME	See CONTACT TIME.
RMS - ROOT MEAN SQUARE	The square root of the average of the square of the instantaneous values throughout a specified period of time; for a periodic quantity the average is taken over one complete cycle (effective value).
SATURATION OZONE CONCENTRATION	Ozone concentration in the liquid phase in equilibrium with the ozone concentration in the gaseous phase (Henry 's law).
SHORT LOOP	See LOOP
SHUT DOWN SYSTEM	An electronic, electric, or pneumatic system designed to shut off and close down process systems or equipment.
SOLUBILITY	Equilibrium concentration of the dissolved gas in a liquid phase at specific conditions depending on pressure, temperature, concentration of ozone in the gas phase and of the characteristics of the liquid phase. The solubility is expressed in mg/l, g/m ³ ..
S.O.T. (SOLUTION OZONE TEST)	See OZONE WATER DEMAND TEST

SPARE EQUIPMENT SPARE PARTS	Equipment complete or in parts, on hand for repair and replacement.
SPECIFIC EXCHANGE AREA	The ratio of the total gas interfacial area to the total volume of liquid.
SPECIFIC POWER CONSUMPTION	See POWER
STANDARDS	IOA formulates recommended procedures for installation and operation of ozone equipment.
STANDBY CAPACITY	See CAPACITY
STANDBY EQUIPMENT	Installed reserve equipment but not in operation.
STANDARD FREQUENCY	See FREQUENCY.
STATIC RADIAL DIFFUSER	Ozone water contacting system in which a partial stream of water is pressurized and mixed with the ozonized gas in a static mixing element located in the head of the turbine. The gas/water mixture is injected into the contactor through nozzles that form fine bubbles due to high shear.
STATIC MIXER	Tool for mixing two fluids (gas or liquid). Ozone water contacting system which consists of mixing elements in series inside a tubular housing. In the case of contacting system, mixing is obtained by mixing ozone gas and water flow.
SUBSTRATE	A molecule present in the fluid or solid to be treated with ozone.
SYSTEM GROUND	See GROUND.
SYSTEM PURGE	See PURGE
TEMPERATURE	The temperature is expressed in Kelvin. It is also commonly measured in Celsius or Fahrenheit degrees. $T(^{\circ}\text{C}) = T(\text{K}) - 273.15$ $T(^{\circ}\text{C}) = 5/9 * (T(\text{F}) - 32)$
TENSION	The French language term for voltage used frequently in the English language in place of voltage, with the same meaning, as in high voltage or high-tension transformer.

THEORICAL HYDRAULIC DETENTION TIME	See CONTACT TIME
THERMAL OZONE DESTRUCTOR	See DESTRUCTOR
THRESHOLD LIMIT UNIT	<p>THRESHOLD LIMIT VALUE - TIME WEIGHTED AVERAGE (TLV-TWA) : 0.1 ppm_v This is the concentration for a normal 8-hour workday and a 40-hour workweek, to which workers may be repeatedly exposed without adverse effect.</p> <p>THRESHOLD LIMIT VALUE - SHORT TERM EXPOSURE LIMIT (TLV-STEL) : 0.3 ppm_v generally. This is the concentration to which workers can be exposed continuously for a short period of time without suffering from irritation or other acute effects provided that the daily TLV-TWA is not exceeded. A TLV-STEL is defined as a 15 minutes time-weighted average exposure which should not be exceeded at any time in a workday. Exposures at the TLV-STEL should not be longer than 15 minutes and should not be repeated more than four times per day. There should be at least 60 minutes between successive exposures at the TLV-STEL.</p>
THYRISTOR	A bistable semiconductor device comprising three or more junctions than can be switched from the off state to the on state or vice versa, such switching occurring within at least one quadrant of the principal voltage-current characteristic.
TRANSFER YIELD	Ratio of the amount of ozone transferred in a liquid or a solid to the amount of ozone introduced or injected in that liquid or solid, given for specific conditions (pH, temperature, and characteristics of the substrate to be treated...) Expressed in %.
TRANSFERRED OZONE DOSE OR RATE	See DOSE
TRANSFORMER	<p>A static electric device with two or more windings to transfer power by electromagnetic induction; it is intended to transform a alternating voltage or alternating current system into another voltage and current system of the same frequency but with changed values.</p> <p>VARIABLE TRANSFORMER : A TRANSFORMER whose output VOLTAGE can be modulated.</p>
TREATMENT RATE or DOSE	See DOSE

TUBULAR DIELECTRIC	See DIELECTRIC
TURBINE CONTACTOR	Ozone water contacting system in which aspirating turbines draw ozonized gas into the contactor and allow the ozone mixing with the water.
U TUBE	Ozonation airlift reactor composed of two concentric cylindrical columns: gas and liquid flow down in co-current in the inner tube and flow up in the annular riser ; the characteristics are : high ozone water transfer and plug flow behavior.
UV ABSORPTION MEASUREMENT	Method according IOA standard 001/97 for the determination of ozone in a process gas. This spectrophotometric method uses the absorption by ozone of wavelengths comprises between 200 and 300 nm (Hartley bands).
VARIABLE INDUCTOR	See INDUCTOR
VARIABLE TRANSFORMER	See TRANSFORMER
VENT GAS	The gas which is vented from the ozone reactor.
VETERINARY-USE OZONE	Ozone used for therapeutic purposes on animals.
VOLT	The potential difference between two points of a passive circuit carrying a current of one ampere when the power dissipated between these points is one watt.
VOLTAGE	Scalar scale equal to the circulation of an electric field from one point to another along a specified path. (Symbol U - Unit Volt) The electrical voltage is the cause of driving force of the electrical current. ALTERNATING VOLTAGE : A periodic voltage the average value of which is zero. DIRECT VOLTAGE : An electrical voltage of a timely constant amount.

VOLTAGE (CONT'D)	<p>EFFECTIVE VOLTAGE : The square root of the average of the square of the instantaneous values of the voltage taken throughout one period.</p> <p>HIGH VOLTAGE : A relative designation for a range of the electrical voltage. High voltage is in general arbitrarily set as any voltage equal to or greater than 1000 volts.</p> <p>LINE VOLTAGE : The voltage at which the principal power supply is made available to the ozonation process.</p> <p>LOW VOLTAGE : A relative designation for a range of the electrical voltage. Low voltage is in general arbitrarily set as any voltage smaller than 1000 volts.</p> <p>OPERATING VOLTAGE : The electrical alternating voltage available in the main power supply. Typical operating voltage are 110, 220, 380, 440, 600 and 680 volt for example.</p>
VPSA VACUUM PRESSURE SWING ADSORPTION	Process used to separate the air components (mainly nitrogen and oxygen) by selective adsorption on adsorbent like molecular sieve (like zeolite) operating at pressure above atmosphere. Regeneration is achieved under vacuum and production under pressure.
VSA VACUUM SWING ADSORPTION	Process used to separate air components (principally nitrogen and oxygen) by selective adsorption on adsorbent like molecular sieve (like zeolite). The adsorption pressure is close to atmosphere. The regeneration phase or desorption is achieved through vacuum.
WATER COOLED	See COOLING
WATER SEPARATOR	A component whose purpose is to separate water from a gas or a liquid immiscible with water.



VI. OZONE-RELATED CONVERSION TABLES

LENGTH

METRE	INCH	FOOT	YARD
m	in	ft	yd
1	39.37	3.2808	1.0939
0.0254	1	0.0833	0.0278
0.3048	12	1	0.3333
0.9144	36	3	1

AREA

m²	in²	ft²	yd²	ACRES	HECTARES
1	1550	10.764	1.196	---	---
6.45x10 ⁻⁴	1	6.94x10 ⁻³	7.72x10 ⁻⁴	---	---
0.0929	144	1	0.1111	---	---
0.836	1296	9	1	---	---
4047	---	43,560	4840	1	0.4047
10,000	---	107,640	11,960	2.471	1

VOLUME

Note: 1 litre water = 1 kg

m³	litre	ft³	GAL	GAL	WATER
	l		(US)	(UK)	lb
1	1000	35.315	264.2	220	2204.6
0.001	1	0.0353	0.2642	0.22	2.2046
0.0283	28.3168	1	7.48	6.229	62.428
0.003785	3.785	0.1337	1	0.8327	8.3454
0.004546	4.546	0.1605	1.201	1	10.022

WEIGHT

kg	METRIC TON (TONNES)	LONG TON (UK)	SHORT TON (US)	POUND lb
1	0.001	0.00098	0.0011	2.2046
1000	1	0.9842	1.1023	2204.62
1016	1.0161	1	1.12	2240
907.19	0.9072	0.8929	1	2000
0.45359	4.546x10 ⁻⁴	4.464x10 ⁻⁴	5.0x10 ⁻⁴	1

FLOW

m ³ /h	l/sec	cfm	gpm (UK)	gpm (US)	mgd (US)
1	0.278	0.59	3.37	4.4	0.00634
3.6	1	2.12	13.2	15.85	0.0228
1.7	0.47	1	6.23	7.48	0.0108
0.273	0.076	0.16	1	1.2	0.0017
0.227	0.063	0.13	0.83	1	0.00144
157.7	43.8	92.8	578	694	1

ENERGY AND BEAT

Note: 1 Joule = 1 Watt sec = 1 Newton metre

JOULE	CAL	kWh	kg(f) m	ft lb
1	0.2389	0.278x10 ⁻⁶	0.10197	0.7376
4.186	1	1.164x 10 ⁻⁶	0.4268	3.0875
3.6x10 ⁶	859,353	1	366,799	2.65x10 ⁶
9.8068	2.343	2.726x 10 ⁻⁶	1	7.2335
1.3557	0.324	0.377x10 ⁻⁶	0.1382	1

POWER

Note: 1 Watt = 1 Joule/sec

WATT	cal/s	kg(f) ms	HP	kW
1	0.2389	0.10197	0.00134	0.001
4.186	1	0.427	0.0056	0.00419
9.8068	2.343	1	0.01315	0.00981
746	178.15	76.04	1	0.746
1000	238.9	101.97	1.341	1

DOSAGE

kg/m ³	lbs/GAL	lbs/GAL	ozs/GAL	ozs/GAL
mg/l	(US)	(UK)	(US)	(UK)
1	0.00835	0.01002	0.1335	0.16036
119.826	1	1.201	16	19.215
99.776	0.8327	1	13.323	16
7.489	0.0625	0.0751	1	1.201
6.236	0.052	0.0625	0.8327	1

PRESSURE**Note:**1 Pascal = 1 Newton/m²

1 kPa = 1000 Pascal

1 torr = 1 mm Hg

kPa	BAR	atm	psi	Hg mm	Hg in	Water m	Water ft	kg(f)/ m ²	kg(f)/ cm ²	lb/ft ²
1	0.01	0.00987	0.145	7.5	0.2953	0.102	0.3345	101.97	0.010197	20.885
100	1	0.987	14.5	750	29.53	10.2	33.45	10,197	1.0197	2088.5
101.325	1.01325	1	14.696	760	29.92	10.332	33.90	10,332	1.0332	2116.22
6.895	0.06895	0.068	1	51.71	2.036	0.7031	2.307	703	0.703	144
0.1333	0.00133	0.01316	0.0193	1	0.0394	0.0136	0.0446	13.596	0.00136	2.785
3.386	0.03386	0.03342	0.4912	25.4	1	0.3453	1.133	345.34	0.0345	70.732
9.807	0.09807	0.09678	1.4224	73.551	2.896	1	3.281	1000	0.1	204.82
2.989	0.02989	0.0295	0.4335	22.419	0.8826	0.3048	1	304.80	0.0305	62.43
0.0098	9.8x10 ⁻⁵	9.7x10 ⁻⁵	0.00142	0.0736	0.0029	0.001	0.00328	1	0.0001	0.2048
98.068	0.9807	0.9679	14.2236	735.5	28.957	10	32.81	10,000	1	2048
0.04788	0.000479	0.000473	0.00694	0.359	0.0141	0.00488	0.016	4.882	0.000488	1

MOLECULAR MASS

ELEMENT	DENSITY ρ_0	kg(mass)/m ³ (NTP)
Argon (Ar)	39.9	1.784
Carbon Dioxide (CO ₂)	44.0	1.977
Dinitrogen Pentoxide (N ₂ O ₅)	108.0	1.642
Methane (CH ₄)	16.0	0.717
Nitrogen (N ₂)	28.0	1.251
Oxygen (O ₂)	32.0	1.429
Ozone (O ₃)	48.0	2.144
Standard dry air	28.8	1.293
Water vapour	18.0	0.804

DENSITY OF GAS

Dry $\rho = \rho_0 (T_0/T)(P/P_0)$

Moist $\rho = \rho_0 (T_0/T) (P - 0.3783\Pi) / P_0$

Where Π = partial pressure of the water

$$\% \text{ O}_3 \text{ (mass)} = \frac{100 \times C_{\text{O}_3}}{\rho_0 \text{ feed gas } (1 + C_{\text{O}_3} / 2 \rho_{\text{O}_3})}$$

or

$$\% \text{ O}_3 \text{ (mass)} = \frac{100 \times C_{\text{O}_3}}{\rho_0 \text{ feed gas } (1 + 2.33 \times 10^{-4} C_{\text{O}_3})}$$

where: C_{O_3} = ozone concentration (g/m³ NTP)
 ρ_0 = gas density (g/m³ NTP)