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International Standard

ISO 4240-2

Fine bubble technology — Environmental applications —

Part 2:
Test method for evaluating aeration performance of fine bubble jet devices

Technologie des fines bulles — Applications environnementales —

Partie 2: Méthode d'essai pour l'évaluation des performances d'aération des diffuseurs à fines bulles

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Contents

Foreword

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This document was prepared by Technical Committee ISO/TC 281, *Fine bubble technology*.

A list of all parts in the ISO 4240 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Recent progress in the application of fine bubble technology demonstrates success in various technical fields. Fine bubble jet devices are generally applied in a pure oxygen aeration process to improve the oxygen transfer from gas phase to liquid phase in the environmental engineering fields, such as wastewater treatment and water ecological restoration. Small size jet devices (≤ 1 m^3/h) are often used for cleaning. Medium size jet devices (1 to 10) m^3/h are often used in aquaculture and agricultural fields. Large size jet devices (≥ 10 m^3/h) are often used for water treatment and water environment restoration. The fine bubble jet devices are operated in ejector mode (self-aspiration) or injector mode (pressurized oxygen supply). The mode of operation affects the achievable mass transfer and its energy efficiency.

To evaluate aeration device performance there is a need for a standard method for oxygen transfer measurements which can be applied for all types of fine bubble jet devices.

This document is intended to specify the test procedure to be applied to the fine bubble jet devices for oxygen aeration uses. Based on the performance data presented by each bubble generator manufacturer, the engineers who designed the aeration process can calculate how many generators should be used to meet the use requirements.

Fine bubble technology — Environmental applications —

Part 2:
Test method for evaluating aeration performance of fine bubble jet devices

1 Scope

This document describes the test methodology to evaluate the aeration performance of fine bubble jet devices based on an evaluation of the mass transfer coefficient of oxygen from gas to water.

It is applicable to evaluate the performance of fine bubble jet devices for aeration purpose.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20480-1, *Fine bubble technology — General principles for usage and measurement of fine bubbles — Part 1: Terminology*

ISO 20480-2, *Fine bubble technology — General principles for usage and measurement of fine bubbles — Part 2: Categorization of the attributes of fine bubbles*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 20480-1, ISO 20480-2 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
aeration
oxygenation
process of introducing of air/oxygen into a body of water to increase its oxygen saturation

3.2
pure oxygen
gas containing more than 90 % oxygen

3.3
fine bubble jet device
device that accelerates and releases fluid with fine bubbles, including swirling flow system, ejector system and venture system

3.4
oxygen mass transfer coefficient
$K_{L,a}$
parameter used to assess rates of oxygen transfer from air to water

Note 1 to entry: Expressed in h^{-1} or min^{-1}.

3.5
DO
amount of dissolved oxygen in water or other liquids

Note 1 to entry: Expressed in mg/l.

3.6
standard oxygen transfer efficiency
SOTE
quantity of the introduced oxygen that dissolves in water under standard conditions

Note 1 to entry: The standard conditions are *T*: 293,15 K (20 °C), *P*: 101,325 KPa (mass %).

3.7
standard oxygen transfer rate
SOTR
oxygen mass transfer rate at standard conditions

Note 1 to entry: The standard conditions are *T*: 293,15 K (20 °C), *P*: 101,325 KPa (kg-O_2/h).

3.8
standard aeration efficiency
SAE
mass of oxygen transferred per unit energy at standard conditions

Note 1 to entry: The standard conditions are *T*: 293,15 K (20 °C), *P*: 101,325 KPa (kg-O_2/kW-h).

3.9
cycle frequency
ratio of circulating water flow rate to tank volume

Note 1 to entry: Expressed in h^{-1}.

4 Principle of aeration performance test

Aeration (oxygenation) is an oxygen mass transfer process. Gas liquid mass transfer is highly affected by the generation of gas liquid interface. During the transfer of oxygen from the gas phase to the liquid phase, the resistance mainly comes from the liquid film, the oxygen mass transfer coefficient ($K_{L,a}$) should be given by the following Formula (1). Integrating and sorting Formula (1) gives Formula (2).

$$\frac{dC}{dt} = K_{L,a}\left(C_\infty^* - C\right) \tag{1}$$

$$\ln\left(C_\infty^* - C\right) = \ln\left(C_\infty^* - C_0\right) - K_{L,a} \cdot t \tag{2}$$

where

C is the dissolved oxygen concentration in water corresponding to the aeration time t [mg/l];

t is the aeration time [min];

C_0 is the dissolved oxygen concentration value at the test point at time 0 [mg/l];

C_∞^* is the dissolved oxygen concentration value when the test point reaches a steady state [mg/l].

Therefore, $K_{L,a}$ value can be obtained from an aeration experiment in clean water by taking DO measurements over time.

According to the $K_{L,a}$ value obtained in the aeration experiment, the $K_{L,as}$ value at different temperatures should be calculated by Formula (3).

$$K_{L,as} = K_{L,a} \times \theta^{20-T} \tag{3}$$

where

$K_{L,as}$ is the oxygen mass transfer coefficient under standard conditions (T: 293,15 K (20 °C) P: 101,325 KPa) [1/min]:

θ is the temperature correction empirical coefficient, may take 1,024;

T is the water temperature, which is the average temperature during the test [°C].

The standard oxygen mass transfer rate (SOTR, kg/h) should be calculated according to Formulae (4)-(8).

$$O_{TR,S} = \frac{1}{n} \sum_{i=1}^{n} O_{TR,S,i} \tag{4}$$

$$O_{TR,S,i} = 0,06 \times K_{L,as,i} \cdot C_{\infty 20 i}^* \cdot V \tag{5}$$

$$C_{\infty 20 i}^* = \frac{C_{\infty i}^*}{\tau \cdot \eta} \tag{6}$$

$$\tau = \frac{C_{st}^*}{C_{s20}^*} \tag{7}$$

$$\eta = \frac{P_b}{P_{b0}} \tag{8}$$

where

$O_{TR,S,i}$ is the standard oxygen mass transfer rate (SOTR) at the i th test or test point [kg/h];

$K_{L,as,i}$ is the standard oxygen mass transfer coefficient at the i th test or test point [1/min];

$C_{\infty 20 i}^*$ is the saturated dissolved oxygen concentration at the i th test or test point under the standard state (T: 293,15 K (20 °C) P: 101,325 KPa) [mg/l];

V is the volume of water in the oxygen aeration tank [m³];

$C_{\infty i}^*$ is the steady-state saturated dissolved oxygen concentration at the i th test or test point [mg/l];

τ is the temperature correction factor;

η is the pressure correction factor;

C_{st}^* is the saturated dissolved oxygen concentration value at 101,325 kPa atmospheric pressure and test water temperature [mg/l];

C_{s20}^* is the saturated dissolved oxygen concentration value under the standard state (T: 293,15 K (20 °C) P:101,325 KPa) [mg/l];

P_b is the absolute pressure of the gas during the test [kPa];

P_{b0} is the standard atmospheric pressure, 101,325 kPa.

Standard aeration efficiency (SAE, kgO$_2$/kWh) should be calculated according to Formula (9):

$$A_{E,S} = \frac{O_{TR,S}}{P} \tag{9}$$

where

$O_{TR,S}$ is the standard oxygen transfer rate [kg/h];

A_{ES} is the standard aeration efficiency (SAE) [kgO$_2$/kWh]

P is the gross effective power input [kW], and for self-aspiration jet device it includes the pump power; while for a fine bubble jet device applied by a blower, the power consumption [kW] includes the power applied by both water flow and the gas flow.

Standard oxygen transfer efficiency (SOTE) describes how much of the injected oxygen becomes dissolved in water. It is expressed as a percentage with Formula (10). SOTE is determined by the SOTR and the injected flow of oxygen.

$$O_{TE,S} = \frac{O_{TR,S}}{W_{o2}} \cdot 100 \tag{10}$$

where

$O_{TE,S}$ is the standard oxygen transfer efficiency [%];

W_{o2} is the oxygen mass flow [kg/h], which should be calculated by Formulae (11) - (13).

$$W_{O2} = a \cdot q \tag{11}$$

$$a = y \cdot \frac{P_b \cdot M}{8,314 \cdot T_b} \tag{12}$$

$$q = \frac{q_b \cdot P_b \cdot T_{b0}}{T_b \cdot P_{b0}} \tag{13}$$

where

a is the density of gas at standard state [kg/m^3];

y is the proportion of oxygen (for air, 0,21);

P_b is the absolute pressure value of the gas pressure displayed by the barometer on the test site [KPa];

M is the gas molar mass [g/mol];

T_b is the temperature of the on-site gas in the absolute thermometer during the test, $T_b = T + 273$ [K];

T is the temperature of the gas on site during the test [°C];

q is in standard state, the volume flow of oxygen entering the fine bubble jet device suction chamber [m^3/h];

T_{b0} is the absolute temperature 273 K.

5 Test system for aeration performance test

5.1 Test system

The test system is shown in Figure 1.
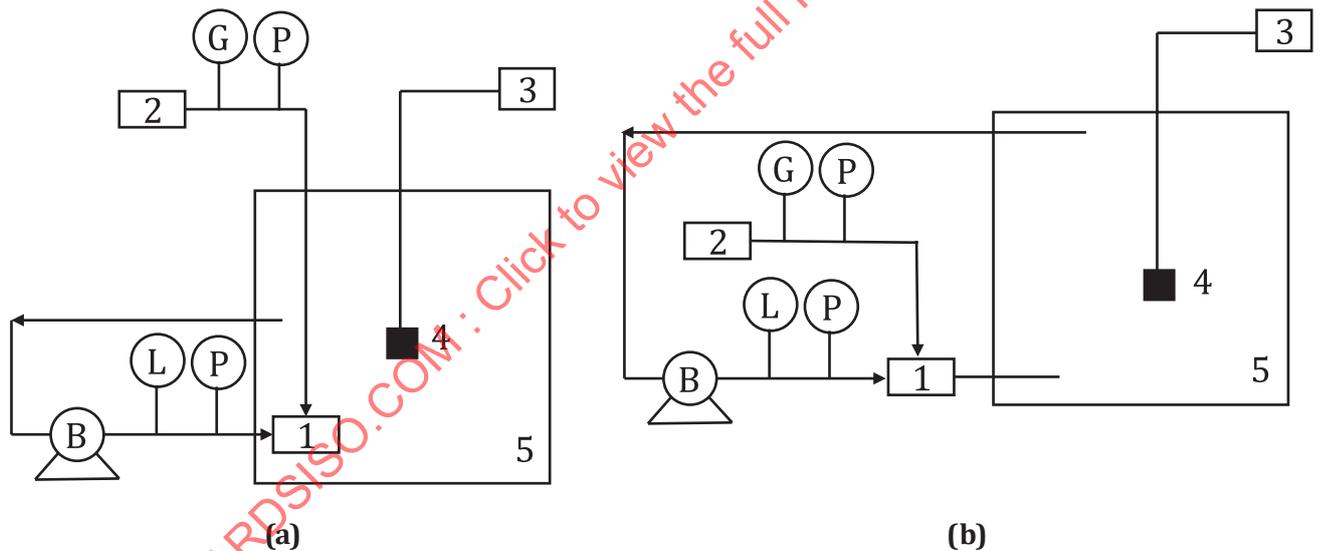
Key

1	fine bubble jet device	B	pump
2	oxygen	L	water flowmeter
3	DO monitor	G	oxygen flowmeter
4	DO sensor	P	pressure gauge
5	tank		

Figure 1 — Configuration of test system

An example of test system is show in the Figure A.1 in Annex A.

5.2 Supplied materials for test

The volume of test tank should be determined according to the cycle frequency, which should be larger than 10 h^{-1}. Therefore, the test water volume (m^3) should be larger than 1/10 of the circulating water flow rate (m^3/h). The water depth should be less than 1 m.

The DO sensor accuracy should be ±0,5 %, response time should be less than $0{,}02/K_{L,a}$.

The DO should be measured by the optical sensor method. The upper range should be 500 % air saturation for oxygen aeration.

The oxygen gas volume should be measured by a gas flow meter with an accuracy of ±2 %.

The water temperature should be measured by a thermometer with an accuracy of ±0,1 %.

The gas flow rate should be measured by a mass flow meter. If a volumetric flow meter is used, it should be converted to mass flow rate.

5.3 Preparation for test

Install the DO sensors at the specific position, test the dissolved concentration of oxygen, if the difference in average concentration in different positions is less than 1 %, then select the centre of the tank for analysing.

Turn on the DO monitor to warm up 0,5 h in advance and calibrate the DO sensor.

Fill the device with water to the required level.

The test water shall be ultra-pure water or deionized water. The test water temperature should be 23,5 ± 3,5 °C.

5.4 Preliminary test for confirmation of reproducibility

The experiments should be conducted in triplicate, and an average $K_{L,a}$ value should be reported.

6 Test procedures

6.1 Sodium sulphite

The detection method adopts the non-steady-state measurement method, and the water in the aeration tank cannot enter or exit. Cobalt chloride is used as a catalyst, and sodium sulphite is used as a deoxidizing agent.

Water-free, commercial sodium sulphite (Na_2SO_3) is employed which is oxidised to sodium sulphate (Na_2SO_4) by the oxygen dissolved in the water. 8 kg of Na_2SO_3 are necessary for the bonding of 1 kg oxygen. The solubility of Na_2SO_3 at $T = 10\ °C$ is approximately 195 kg/m^3. The Na_2SO_3 solution should be made by dissolving 100 kg Na_2SO_3 into 1,0 m^3 water.

The DO concentration can be also depleted by sparging nitrogen gas until measuring a DO concentration below 0,5 mg/l when restricted by drug conditions. Simultaneously, the total of dissolved solids should be less than 600 mg/l.

6.2 Cobalt catalyst

Cobalt in the form of a cobalt salt, e.g. $CoCl_2 \cdot 6H_2O$, is added as a catalyst to accelerate the oxidation of sodium sulphite. A cobalt concentration in water of 0,5 g/m^3 should be used, but in many cases a tenth of this concentration suffices.

If several tests are to be carried out in an aeration tank with the same water, cobalt salt should be added once only. The required quantity of cobalt, dissolved in warm water, should be added sufficiently early so that it is distributed evenly over the entire tank at the time of the addition of the sodium sulphite.

6.3 Operation of fine bubble generator

Turn on the pump and regulate the gas flow rate to specific value.

6.4 Recording of DO concentration

Record the dissolved oxygen concentration in the water at different times during the aeration stage, and obtain the relationship between the dissolved oxygen concentration at each test point over time. The signals from all DO probes shall be recorded continuously when absorption measurements are taken. The rising DO curves shall be recorded, without pre-run, for a period of at least $5/K_{L,a}$ (in minutes), see Figure 2. In any case the calculation of $K_{L,a}$ shall be based on at least 30 equidistant values of C.

Key
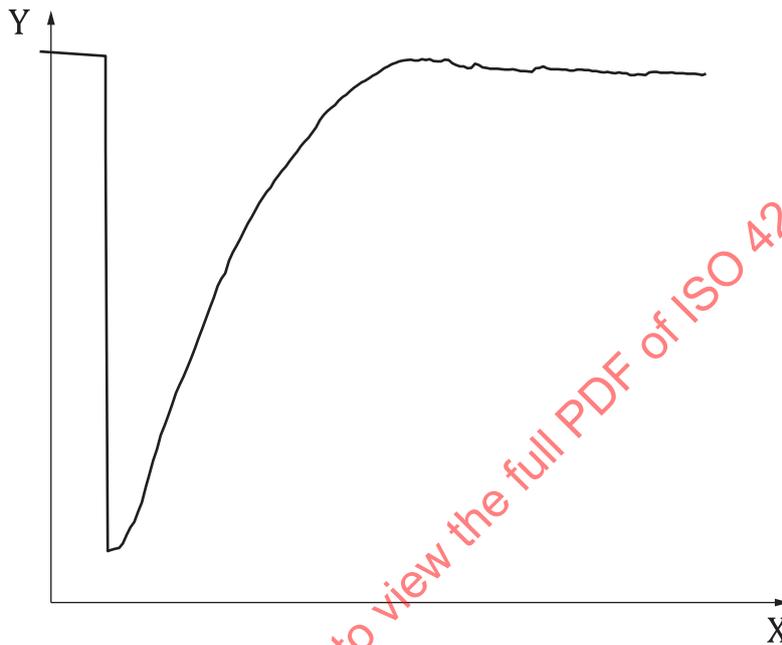
X   time [min]

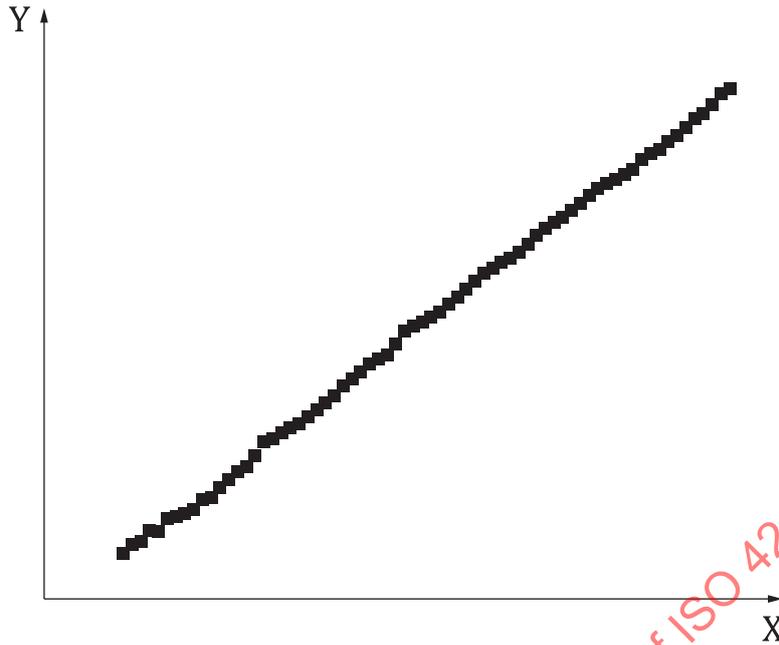Y   concentration of DO [mg/l]

Figure 2 — DO change during the test

6.5 Power input measurement

With every test, the power input should be measured at least twice, at the start and at the end of the test. Test the gas and liquid mass flow rate, as well as the gas pressure (pressurize oxygen supply). With different jet devices, the power consumption can vary; some jet devices need more frequent measurements or the employment of a power recorder is necessary. The individual readings shall be recorded in the test protocol. In each case the mean value is used for the calculation of the aeration efficiency.

7 Method to explain the test results

For all the evaluated experimental conditions, the DO concentration is continuously monitored and recorded in the reactor until reaching a stable DO concentration, see Figure 2. The DO concentration values from 20 % C_∞^* to 80 % C_∞^* are used for calculation of the $K_{L,a}$. The $K_{L,a}$ value is then calculated by performing a non-linear regression using Formula (1) with the aid of the data processing software getting the best fit between the measured DO and time (see Figures A.2 and A.3). The experiments are conducted in triplicate, and an average $K_{L,a}$ value is reported. SOTR, SAE and SOTE are calculated using Formulae (4), (9) and (10), respectively.

An example of values of SAE under different gas flow rates is shown in Figure A.5.

Key

X   time [min]

Y $\dfrac{C_\infty^* - C}{C_\infty^* - C_0}$

Figure 3 — Relationship between concentration of ln Y and time

8 Test report

A report may be prepared in tabular form.

The following information shall be mentioned:

a) a reference to this document, i.e. ISO 4240-2 (including its year of publication);

b) the date of the test;

c) the sample name including manufacturer and model number;

d) a description of the tank and the jet device installation illustrated with drawings. Shown therein the arrangement of the measurement point(s) and the point(s) for chemical dosing;

e) the pressure in front of the jet device injection and liquid flow rate, a description of how the power input is measured, the pressure of gas injection line and gas mass flowrate, a description of how the air flow rate is determined, and a description of the ratio of oxygen and water flowrate;

f) with the employment of Na_2SO_3, description of the water quality with details of the salt content at the beginning and end of each test, the total dissolved solids (TDS) at the beginning of the test, a description of the determination of the requirement for cobalt, and a description of the dissolving, dosing and admixture of sodium sulphite and the mass of sodium sulphite added for each test or corresponding details on stripping the oxygen using nitrogen;

g) the water and air temperature as well as ambient air pressure at the beginning and the end of each test;

h) the water volume, still water level at the start and the end of every test;

i) the table of DO value versus time for each test;

j) the calculation of the $K_{L,a}$ values for each test and the calculation of the mean value for all measurement points of each test, if required, weighted with the associated volume;

k) the result(s), including a reference to the clause which explains how the results were calculated;

l) any deviations from the procedure and any unusual features observed;

m) the measuring unit, entrusted unit, personnel, date and seal.

Annex A
(informative)

Example of test method for evaluating pure oxygen aeration performance of fine bubble jet devices

A.1 General

This annex describes a test method for evaluating oxygen aeration performance of fine bubble jet device and its result on different parameters.

A.2 Preparation

A.2.1 Test system

Test system is as shown in Figure A.1.

The water flow rate during fine bubble generation is kept at 10 m^3/h, while the flow rate of gas is set to 3 l/min, 5 l/min, 10 l/min, 15 l/min and 20 l/min, respectively. The volume of tank is 1 m^3.

Figure A.1 — Configuration of test system

A.2.2 Preparation for test

Install the dissolved oxygen analyser at the centre of the tank used for analysing.

Turn on the dissolved oxygen analyser to warm up 0,5 h in advance and calibrate the dissolved oxygen analyser.

Fill the device with water to the required level.

The test water is tap water and the test water temperature is 20 °C to 25 °C.

A.3   Test procedures

A.3.1   Operation of fine bubble generator

Turn on the pump and regulate the gas flow rate to specific value. The ratio of gas and water should be approximately 1/8.

A.3.2   Recording of concentration of DO

The detection method adopts the non-steady-state measurement method, and the water in the aeration tank cannot enter or exit. Cobalt chloride is used as a catalyst (cobalt concentration in water is 0,5 g/m^3), and sodium sulphite is used as a deoxidizing agent.

The DO concentration values from 20 % C_∞^* to 80 % C_∞^* are used for calculation.

$K_L a$ value is then calculated by performing a non-linear regression using the formula shown in Figure A.3 with the aid of the Microsoft® Excel®[1]) software add-in SOLVER getting the best fit between the measured and calculated DO.

A.3.3   Power input measurement

Measure the power input at the start and at the end of the test. Test the gas and liquid mass flow rate, as well as the gas pressure (pressurize oxygen supply). In each case the mean value is used for the calculation of the aeration efficiency.

A.4   Results of the test

A.4.1   Concentration of DO

Concentration of DO with time is as shown in Figure A.2.

[1)]   Microsoft Excel is the trademark of a product supplied by Microsoft. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.
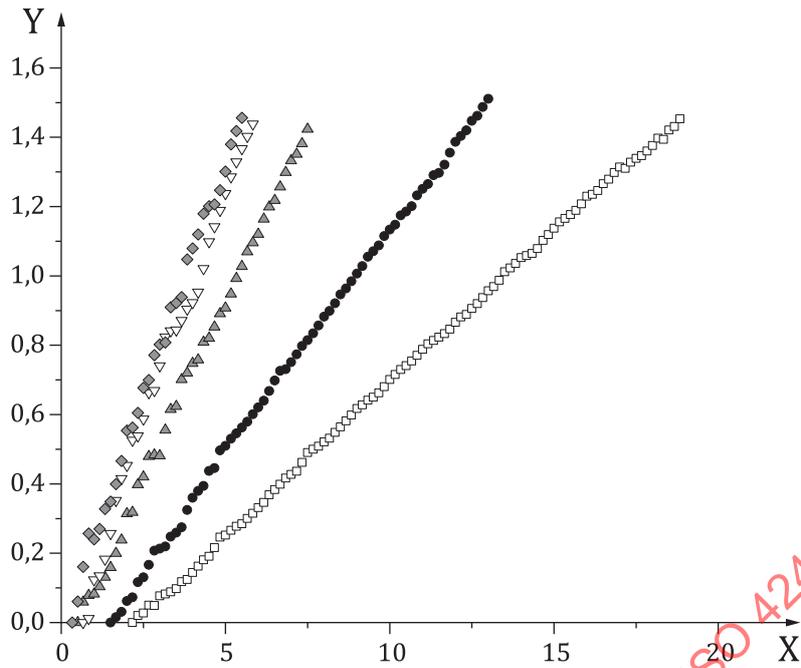
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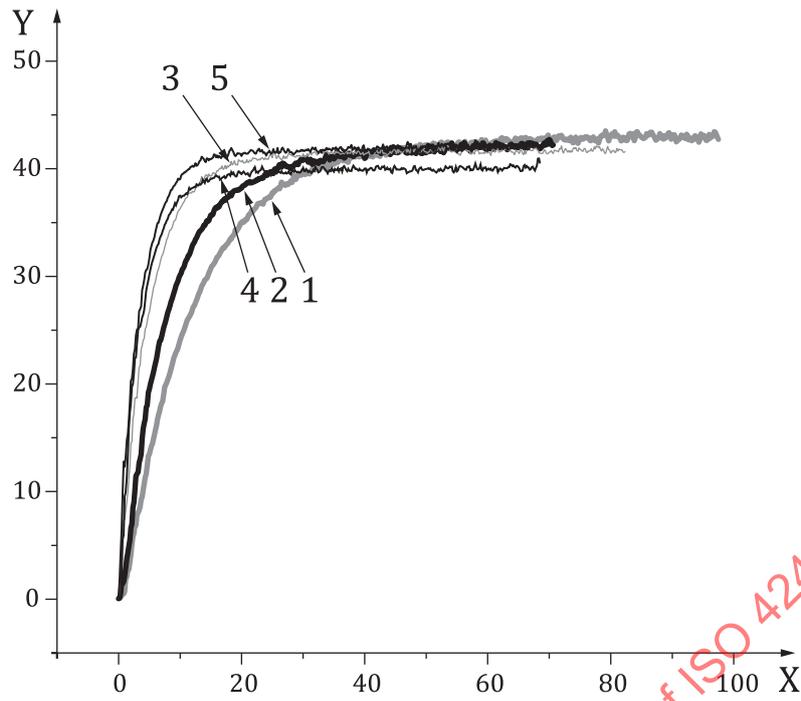
X time [min]

Y concentration of DO [mg/l]

1 3 l/min

2 5 l/min

3 10 l/min

4 15 l/min

5 20 l/min

 NOTE The water flow rate is 10 m³/h.

Figure A.2 — Concentration of DO with time

The process of data analysis to obtain $K_L a$ is as shown in Figure A.3.

Key

X   time [min]

Y $-\ln\left(\dfrac{C_\infty^* - C}{C_\infty^* - C_0}\right)$

☐   3 l/min

●   5 l/min

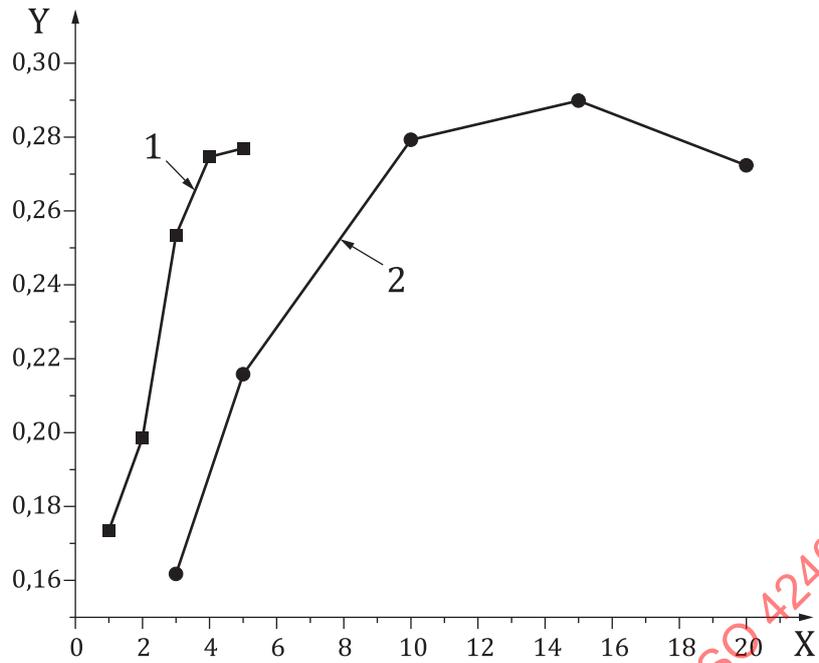▲   10 l/min

▽   15 l/min

◆   20 l/min

NOTE   The water flow rate is 10 m³/h.

Figure A.3 — Data analysis of DO for $K_{L,a}$ calculation

A.4.2 Values of $K_{L,a}$ with different gas flow rates

A fine bubble jet device with a water flow rate of 3 m³/h is also evaluated.

Values of $K_{L,a}$ under different gas fluxes are as shown in Figure A.4.

Key

X   gas flow rate [l/min]

Y   values of $K_{L,a}$ [min^{-1}]

1   3 m^3/h

2   10 m^3/h

Figure A.4 — Values of $K_{L,a}$ under different gas fluxes

A.4.3   Values of SAE with different gas fluxes

Values of SAE under different gas flow rates are as shown in Figure A.5.