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(71) Applicant: **REAL TECH INC.**, [CA/CA]; 1150 Champlain Court, Unit 1, Whitby, Ontario L1N 6K9 (CA).

(72) Inventors: **ORMECI, Banu**; 1141 Willow Brook Way, Manotick, Ontario K4M 1B6 (CA). **GLOVER, Andrew**;

1823 Esterbook Drive, Oshawa, Ontario L1K 0J5 (CA).
KOLLU, Kerim; 1084 Edward Bolton Crescent, Oshawa, Ontario L1K 0T7 (CA).

(74) Agent: **HILL & SCHUMACHER**; 264 Avenue Road, Toronto, Ontario M4V 2G7 (CA).

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(54) Title: A DEVICE FOR DETECTING ALGAE CONCENTRATION USING FIRST DERIVATIVE OF VISIBLE LIGHT ABSORBANCE

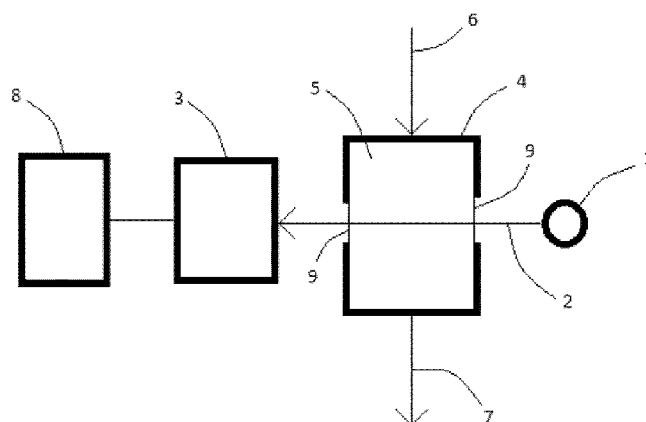


FIGURE 1

(57) Abstract: Monitoring and detection of algae in surface water and wastewater is of significant importance, yet there is currently no quick and simple method to achieve this. The present work illustrates a new method to determine the concentration of algae in water and wastewater samples using spectrophotometry, the first derivative of absorbance, and a smoothing technique applied to the first derivative of absorbance (e.g. Savitzky-Golay). The relationship between algal concentration and absorbance for three types of water samples (distilled, surface, and wastewater) was determined in the visible wavelength range, and the effect of using the first derivative of absorbance method on improving algal concentration detection limit was established. Using the first derivative of absorbance method improves algal detection limits, reduces the effect of background absorbance and the resolution of overlapping spectra. The presence of algae in water can cause a number of problems, and the method presented here can be used to effectively monitor algal concentration



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A DEVICE FOR DETECTING ALGAE CONCENTRATION USING FIRST DERIVATIVE OF VISIBLE LIGHT ABSORBANCE

FIELD

5 The invention relates to the field of visible light spectrophotometry and more particularly it relates to a device for detecting algae concentration using first derivative of visible light absorbance.

BACKGROUND

10 The presence of algae in both surface and wastewater is one of the main causes of water quality deterioration (Al-Zboon and Al-Suhaili, 2009; Rodrigues et al., 2011). Algal growth in different parts of conventional wastewater treatment plants or aerated lagoon systems can result in false indications in the final effluent parameters, such as TSS, CBOD₅ and COD (Heng et al., 2010; Chow et al., 1999; Gitzgerald, 1964). In surface water, the presence of algae
15 creates nuisance surface scum, poor water clarity, and noxious odours (Abdel-Raouf et al., 2012; Aly and Sami, 2014). If this surface water is used to produce drinking water, the algae may lead to problems in the drinking water treatment process, such as reduced filter runs and an increase in the amount of disinfectant needed, which can increase the cost of the treatment (Horan,
20 1990).

 In order to set up an efficient control and treatment process to minimize algal concentration in water samples, it is necessary to have access to a concentration measurement method which is quick, simple, and accurate, and which can detect low algal concentrations in different types of water. The
25 methods currently used to determine algal concentration in different water samples include algal number, as prescribed in the Standard Methods for the Examination of Water and Wastewater (APHA, 1985), and the determination of chlorophyll extract concentration in relation to total algal concentration (Wasmund et al., 2006; Jones and Lee, 1982). Both of these methods are
30 labour and time intensive, expensive, and require extensive laboratory preparation. Moreover, it is not clear how efficient the chlorophyll extraction

process is or how its results are related to the real algal concentration in water solutions.

Recently, the use of real-time and inline spectrophotometric methods at water and wastewater treatment plants to measure different parameters, such as total organic carbon, disinfection by-product precursors, nitrates, and UV transmittance for UV disinfection have increased dramatically (James et al., 2003; Langergraber et al., 2004; Gibbons and Örmeci, 2013; Al Momani and Örmeci, 2014). These measurements are considered practical, quick, simple, and accurate for these industries.

Different studies have reported that the absorbance measurements of algae in water produce a spectrum with a maximum absorbance near the wavelength of red light (540–690 nm) (Gaigalas et al., 2009; UGWU et al., 2007; Liang et al., 2009; Sung et al., 2010). In some types of water and wastewater, the accuracy of the spectrophotometric measurements is affected by water turbidity and by the presence of other constituents in the water sample that mask the absorbance response or produce high levels of noise in the spectral background.

Spectral first and higher-order derivatives have been used by different studies to facilitate the location of the critical wavelength, to reduce low-frequency background noise, and to resolve overlapping spectra (Demetriades-Shah et al., 1990). However, it appears that no research work has explored the use of the first derivative of the absorbance spectra to determine the concentration of algae in an aqueous solution.

The foregoing examples of the related art and limitations related therewith are intended to be illustrative and not exclusive. Other limitations of the related art will become apparent to those of skill in the art upon a reading of the specification and a study of the figures.

SUMMARY

The following embodiments and aspects thereof are described and illustrated in conjunction with systems, tools and methods which are meant to be exemplary and illustrative, not limiting in scope.

There is provided, in accordance with an embodiment, a system for detecting algae, comprising: an online spectrophotometer configured to measure an absorbance level of a sample from a monitored source, and a processor that is configured to apply an algorithm to the measured absorption level to determine the concentration of algae in the monitored source, wherein the detection algorithm is derived by calculating the first derivative of absorbance values for the monitored source and applying a calibration set of the first derivative of absorbance values obtained from a controlled source with known concentrations of algae.

In addition to the exemplary aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the figures and by study of the following detailed description.

Thus the present disclosure provides a device for detecting algae in water, comprising:

- (i) a light source to generate light beams of electromagnetic radiation in the visible light spectrum;
- (ii) a flow cell containing a water sample including windows to allow said light beams to transmit through said flow cell and water sample;
- (iii) a spectrometer unit that receives said transmitted light beam penetrating said sample in said flow cell, and resolves said incident light beam into a specific visible absorbance spectrum pertaining to said sample; and
- (iv) a processor connected to said spectrometer unit programmed to
 - a. compute the derivative of the measured visible absorbance spectrum through said flow cell;
 - b. compute from the derivative spectra the concentration of varying types of algae.

The device is configured to detect the concentration of various algae species.

The device may be operated to measure the concentration of algae in distilled water, surface water, or wastewater.

The processor may be programmed to apply a smoothing technique to improve the signal to noise ratio in the absorbance data. An exemplary non-limiting smoothing technique is the Savitzky-Golay smoothing technique.

The device is constructed so that samples can be directly placed into the spectrometer unit for analysis with no additional sample preparation requirements.

The light source may be a tungsten lamp.

Alternatively, the light source may be an LED based light source.

The spectrometer unit may be a photodiode array based spectrometer.

Alternatively, the spectrometer unit is a monochromator.

The device may be configured to be immersed in a sample water such that the sample water is free to flow in and out of a substantially open flow cell area.

The flow cell is configured to allow sample water to flow through either continuously or in successive batches from a sample source to a sample drain.

A further understanding of the functional and advantageous aspects of the present disclosure can be realized by reference to the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described, by way of example only, with reference to the drawings, in which:

Figure 1 shows the preferred embodiment of the invention, and describes its apparatus.

Figure 2 shows the absorbance scans of various concentrations of *Microcystis aeruginosa* CPCC 299 in deionized water.

Figure 3 shows the Savitzky-Golay first derivative of the absorbance scans of various concentrations of *Microcystis aeruginosa* CPCC 299 in deionized water.

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DETAILED DESCRIPTION

Various embodiments and aspects of the disclosure will be described with reference to details discussed below. The following description and drawings are illustrative of the disclosure and are not to be construed as limiting the disclosure. The Figures are not to scale. Numerous specific details are described to provide a thorough understanding of various embodiments of the present disclosure. However, in certain instances, well-known or conventional details are not described in order to provide a concise discussion of embodiments of the present disclosure.

As used herein, the terms, “comprises” and “comprising” are to be construed as being inclusive and open ended, and not exclusive. Specifically, when used in the specification and claims, the terms, “comprises” and “comprising” and variations thereof mean the specified features, steps or components are included. These terms are not to be interpreted to exclude the presence of other features, steps or components.

As used herein, the term “exemplary” means “serving as an example, instance, or illustration,” and should not be construed as preferred or advantageous over other configurations disclosed herein.

As used herein, the terms “about” and “approximately” are meant to cover variations that may exist in the upper and lower limits of the ranges of values, such as variations in properties, parameters, and dimensions. In one non-limiting example, the terms “about” and “approximately” mean plus or minus 10 percent or less.

Unless defined otherwise, all technical and scientific terms used herein are intended to have the same meaning as commonly understood to one of ordinary skill in the art.

An embodiment of the invention includes the apparatus described by **Figure 1**. A light source **(1)** provides light of the required wavelengths for detection of the various algae species to be detected in water, generally in the red light region of the visible spectrum. In the preferred embodiment the light source **(1)** is a broadband light source in the visible light spectrum, where the broadband light source could be a tungsten lamp, or an LED based light source. A light beam **(2)** from the light source transmits through a flow cell **(4)** containing the water sample under test **(5)** to a spectrometer unit **(3)**. The flow cell allows sample water to flow through either continuously or in successive batches. In the preferred embodiment the sample water flows from a sample source **(6)** to a sample drain **(7)** continuously. The flow cell **(4)** contains windows **(9)** to allow the light to transmit through the flow cell. Note that in another embodiment the system could be immersed in a sample fluid such that the sample water is free to flow in and out of a substantially open flow cell area. The spectrometer unit **(3)** resolves the incident light into a specific absorbance spectrum of the water sample under test **(5)** as shown in **Figure 2**. A computer system **(8)** connected to the spectrometer unit **(3)** has been programmed specifically to compute the first derivative of the measured absorbance spectrum through the flow cell, apply a smoothing technique to the first derivative (such as, but not limited to, the Savitzky-Golay technique as shown in **Figure 3**), and to compute the concentration of various types of algae from the first derivative of absorbance spectra.

The foregoing description of the preferred embodiments of the invention has been presented to illustrate the principles of the invention and not to limit the invention to the particular embodiment illustrated. It is intended that the scope of the invention be defined by all of the embodiments encompassed within the following claims and their equivalents.

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WHAT IS CLAIMED IS:

1. A device for detecting algae in water, comprising:
 - (v) a light source to generate light beams of electromagnetic radiation in the visible light spectrum;
 - (vi) a flow cell containing a water sample including windows to allow said light beams to transmit through said flow cell and water sample;
 - (vii) a spectrometer unit that receives said transmitted light beam penetrating said sample in said flow cell, and resolves said incident light beam into a specific visible absorbance spectrum pertaining to said sample;
 - (viii) a processor connected to said spectrometer unit programmed to:
 - a. compute the derivative of the measured visible absorbance spectrum through said flow cell;
 - b. compute from the derivative spectra the concentration of varying types of algae.
2. A device for detecting algae according to claim 1 wherein said device can detect the concentration of various algae species.
3. A device for detecting algae according to claims 1 or 2 wherein said device can be operated to measure the concentration of algae in distilled water, surface water, or wastewater.
4. A device for detecting algae according to claims 1, 2, or 3 wherein said processor is programmed to apply a smoothing technique (e.g. Savitzky-Golay) to improve the signal to noise ratio in the absorbance data.

5. A device for detecting algae according to claim 4 wherein said smoothing technique is the Savitzky-Golay smoothing technique.
6. A device for detecting algae according to any one of claims 1 to 5 wherein samples can be directly placed into said spectrometer unit for analysis with no additional sample preparation requirements.
7. A device for detecting algae according to any one of claims 1 to 6 wherein said light source is a tungsten lamp.
8. A device for detecting algae according to any one of claims 1 to 6 wherein said light source is an LED based light source.
9. A device for detecting algae according to any one of claims 1 to 8 wherein said spectrometer unit is a photodiode array based spectrometer.
10. A device for detecting algae according to any one of claims 1 to 8 wherein said spectrometer unit is a monochromator.
11. A device for detecting algae according to any one of claims 1 to 10 wherein said device could be immersed in a sample water such that the sample water is free to flow in and out of a substantially open flow cell area.
12. A device for detecting algae according to any one of claims 1 to 10 wherein said flow cell allows sample water to flow through either continuously or in successive batches from a sample source to a sample drain.

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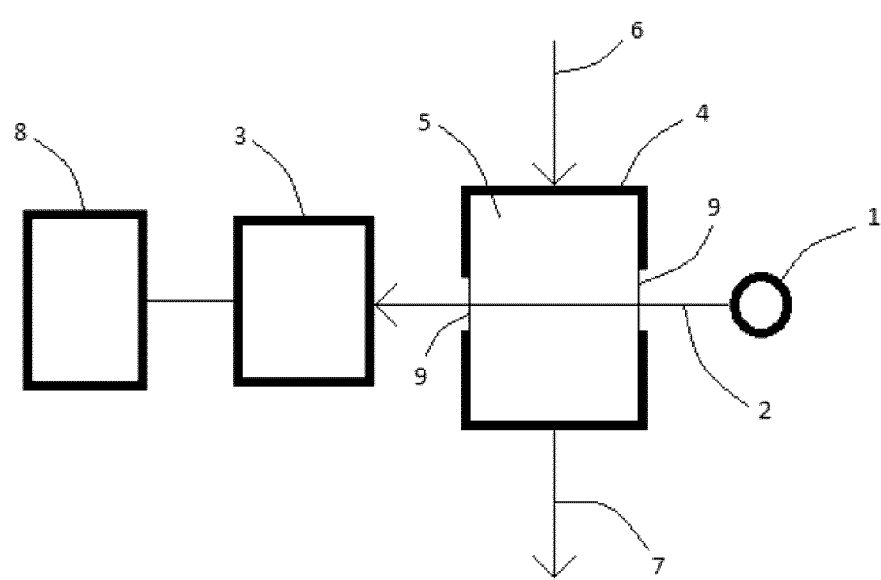
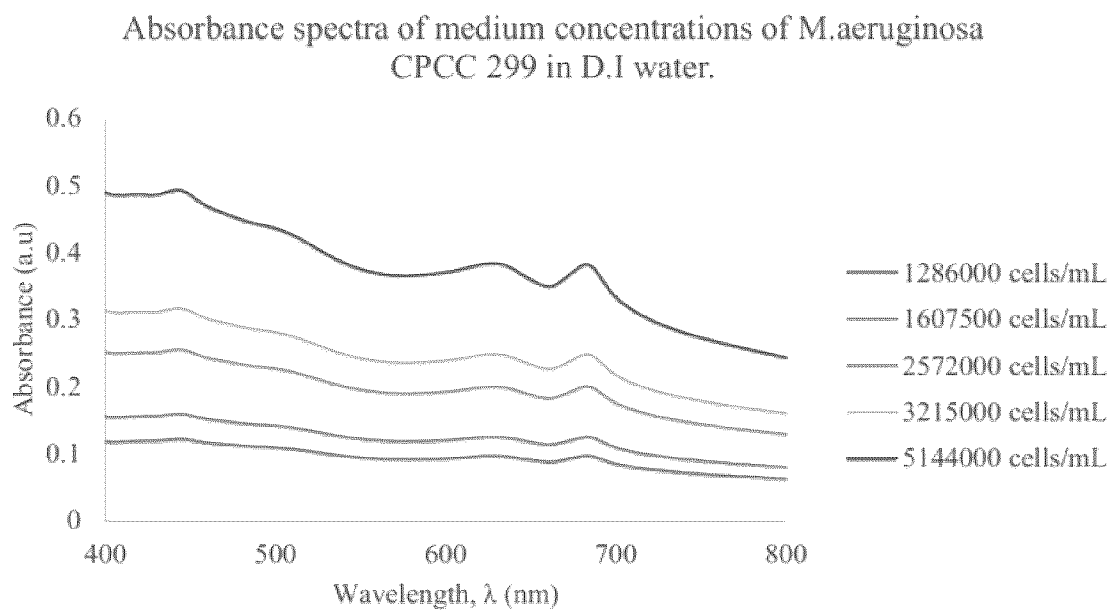


FIGURE 1

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**FIGURE 2**

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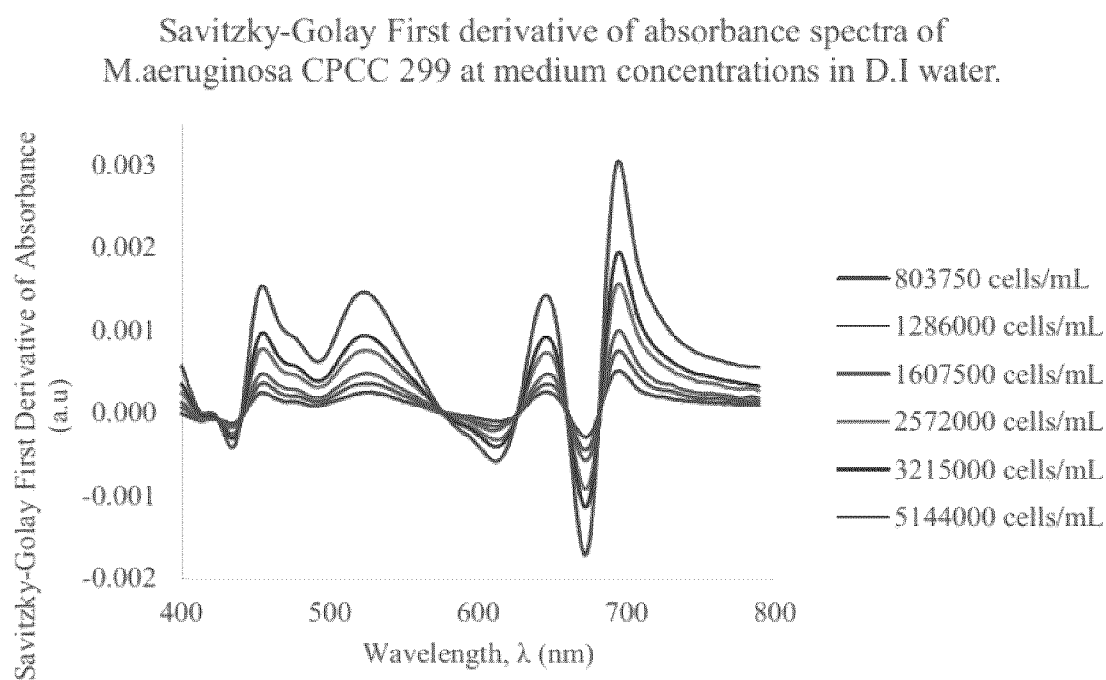


FIGURE 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2017/050629

A. CLASSIFICATION OF SUBJECT MATTER
IPC: **G01N 21/27** (2006.01), **G01J 3/10** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: G01N 21/27 (2006.01), G01J 3/10 (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Questel Orbit, Google (keywords: visible spectroscopy algae water first derivative absorbance etc.)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Rundquist et al. "Remote Measurement of Algal Chlorophyll in Surface Waters: The Case for the First Derivative of Reflectance Near 690 nm." Photogrammetric Engineering & Remote Sensing. Vol. 62, No. 2, February 1996 (02-1996), pp. 195-200	1-12
A	WO 2014156363 A1 KAKU HIROKAZU 02 October 2014 (02-10-2014)	1-12
A	SANCHEZ et al. "Derivative Ultraviolet-Visible Region Absorption spectrophotometry and its analytical applications." Talanta, Vol. 35, No. 10, pp. 753-761, 1988 (1988)	1-12

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* "A" "E" "L" "O" "P"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance earlier application or patent but published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	"T" "X" "Y" "&"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art document member of the same patent family
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Authorized officer

Anthony Glaser (819) 639-3193

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Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
WO 2014156363 A1	02-10-2014	JP 2014187962 A	06-10-2014