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Development of a tri-parameter online monitoring system for UV disinfection reactors

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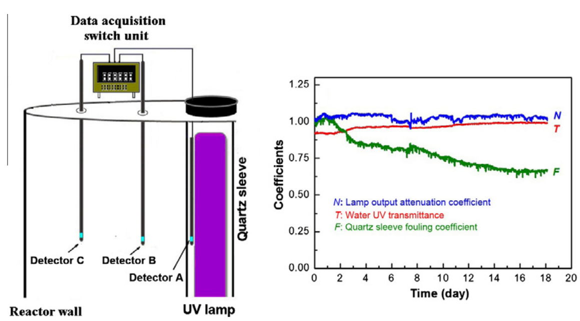
HIGHLIGHTS

- A tri-parameter online monitoring system was developed for UV disinfectors.
- This system could monitor lamp attenuation, water transmittance and sleeve fouling.
- Water temperature had a significant effect on the lamp output.
- A long-term experiment demonstrated the applicability of this monitoring system.

GRAPHICAL ABSTRACT



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ABSTRACT

Online monitoring of an ultraviolet (UV) facility not only can ensure disinfection efficiency, but also conserve energy. In this work, a tri-parameter online monitoring system was developed by using three micro-fluorescent silica detectors (MFSDs) installed into a UV disinfection reactor. The detector signals were computed by theoretically derived mathematical equations to determine three key operational parameters: the lamp output attenuation coefficient (N), water UV transmittance (T), and quartz sleeve fouling coefficient (F). Results indicate that the N, T and F parameters could be monitored well by the MFSDs. The monitored lamp output exhibited a significant dependence on water temperature; the monitored water transmittance was verified by a UV–Vis spectrophotometer; and the monitored sleeve fouling coefficient decreased from 1.00 to 0.66 after an 18-day operation with a synthetic hard water. A long-term 30-day experiment, where the UV reactor was directly connected to a tap water faucet to simulate practical conditions, demonstrated the good applicability of the developed monitoring system. This monitoring system in real time can be used to adjust the number of operating lamp modules, alarm any accidental breakdown of the lamps, and trigger auto-cleaning of the quartz sleeves, thus having potential applications to open-channel and enclosed UV disinfection facilities.

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1. Introduction

Over the past several decades, ultraviolet (UV) technology has been used worldwide for water and wastewater treatment [1–3]. Online monitoring of a UV disinfection facility can greatly improve disinfection safety and allow energy conservation as well. In particular, online monitoring of key operational parameters, as part of an intelligent central control system, has become increasingly popular in the field of water and wastewater treatment [4–7].

Nevertheless, many factors, such as the fouling of quartz sleeves, the aging of lamps and ballasts, and the variations of water flow rate, temperature and quality, can all affect significantly the delivered UV fluence, which in turn will influence the performance of a UV facility [8–11]. In fact, a UV disinfection facility is often forced to operate at a higher fluence from calculations in the design

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Nomenclature

A, *B*, *C*	real-time signals of detectors A, B and C, respectively	MFSD	micro-fluorescent silica detector
A_r, B_r, C_r	reference signals of detectors A, B and C, respectively	*N*	lamp output attenuation coefficient
F	sleeve fouling coefficient	SHW	synthetic hard water
L	effective path length of UV light (cm)	*T*	water transmittance
LP	low pressure		

process [12–15] than required by regulations due to a lack of real-time control based on monitoring of operational parameters. This leads to excess energy consumption for routine operations and possibly ineffective treatment of water and wastewater because of the lack of an alarm when an accident (e.g., lamp breakdown) occurs. Thus, online monitoring of key operational parameters, which then allows a calculation of the real-time fluence, combined with an initial bioassay-validated fluence [16–19], should be of essential importance. Moreover, the availability of these real-time parameters allows a related intelligent central control system to automatically adjust the fluence by turning on/off some lamp modules or alarm any breakdown of the UV facility, thus largely increasing the disinfection safety.

Routine parameters, such as water flow rate, water temperature, and lamp age, can now be monitored readily by commercially available sensors. In addition, some UV intensity sensors have been installed in UV facilities to monitor a lumped index of the real-time operating status [20–22]. However, monitoring methods for some other critical parameters, such as the lamp output attenuation coefficient, quartz sleeve fouling coefficient and water transmittance, have not been well developed. As a result, the currently available UV sensors cannot guide the operation and maintenance of UV facilities in real time, such as when to change the lamps and when to clean the quartz sleeves.

In our previous work, a novel micro-fluorescent silica detector (MFSD) has been developed that can provide in situ measurements of fluence rate distribution in a UV disinfection reactor [23,24]. The MFSD has the merits of high stability (made of durable silica material), extremely fast response (~1 μs) and very small volume (0.07 mm^3), and hence is an ideal sensor for monitoring the operational parameters of a UV facility. For example, because of its small size, the MFSD can be inserted readily into the gap between a low pressure (LP) mercury UV lamp and its quartz sleeve to monitor in real time any drift of the lamp output.

This study aimed to develop a tri-parameter online monitoring system for a UV disinfection reactor by combinational use of the MFSDs. Three critical parameters, including the attenuation coefficient of lamp output, the fouling coefficient of quartz sleeve and the transmittance of water, were acquired through computation of real-time detector signals. Furthermore, the long-term performance of the online monitoring system was also tested under simulated practical conditions.

2. Materials and methods

2.1. Monitoring system

A schematic diagram of the online monitoring and related intelligent central control system is illustrated in Fig. 1. The online monitoring system was established principally using three MFSDs that were installed in the same radial section (about 180 mm below the top cover) in an annular UV disinfection reactor (EX-10, Onyx Company, Beijing, China; inner diameter = 85 mm, reactor length = 900 mm). An LP mercury UV lamp (39 W, Light Sources Co., USA), encircled with a quartz sleeve (23 mm o.d.), was housed

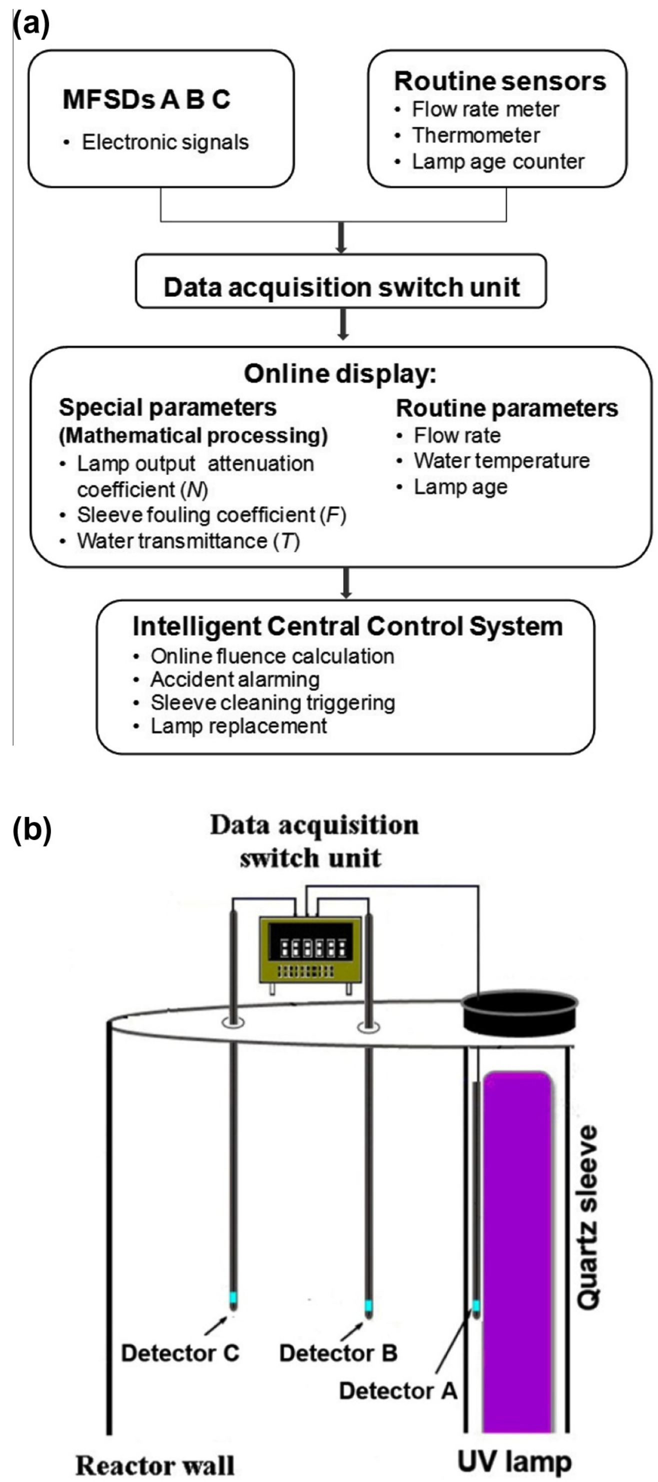

Fig. 1. (a) Flow chart of the online monitoring and intelligent control system and (b) illustration of the online monitoring of a UV disinfection reactor.

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