Optik 155 (2018) 31–35

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Short Communication

A study on optical characteristics and quality monitoring of diesel exhaust fluid

PalaniKumar Gurusamy, Uma Gandhi*, Umapathy Mangalanathan

Department of Instrumentation and Control Engineering, National Institute of Technology, Tiruchirappalli, 620015, India

ARTICLE INFO

Article history:
Received 4 September 2017
Accepted 2 November 2017

Keywords:
Optical measurement
Diesel exhaust fluid
Selective catalytic reduction
NO_X emission
UV–visible-NIR spectrophotometer

ABSTRACT

In an effort to reduce environmental pollution, the urea-Selective Catalytic Reduction (SCR) system is used to reduce NOx emissions from diesel engines with diesel exhaust fluid (DEF) as a reductant. ISO 22241-1:2006 specifies the quality characteristics of the DEF in order to maintain efficiency of the SCR system and hence it is essential that the concentration of urea in DEF is accurately monitored. In this paper an optical based measurement system is proposed for measuring the variation in urea concentration in DEF. The prototype of the measurement system is fabricated with all associated electronics and tested for 1% change in urea concentration with ultraviolet (UV), visible and near-infrared (N-IR) optical source. The measurement system is found to be highly repeatable with a sensitivity of 0.0734 V/% of urea in UV range, 0.0706 V/% of urea in visible range and 0.0595 V/% of urea in IR range. The other contribution of this work includes calculation of molar absorptivity constant and absorbance spectrum of the urea solution at various concentrations using standard UV–visible-NIR spectrophotometer.

1. Introduction

In diesel engines, Selective catalytic reduction (SCR) is one of the promising emission reduction technologies that minimize oxides of nitrogen (NO_X) emission using diesel exhaust fluid and a catalytic converter. Diesel exhaust fluid (DEF) is an aqueous solution with 32.5% of automotive grade urea. The SCR system efficiency is majorly dependent on the 32.5% urea concentration in DEF. The ability of SCR system to minimize NO_X in the exhaust diminishes if foreign matters mix with diesel exhaust fluid and permanent damage may happen to the catalytic converter. Hence, monitoring DEF concentration continuously during engine operation is significant and its quality measurement has become an area of research in recent years [1–3]. A contact type of measurement system for monitoring the quality of DEF solution, by measuring density, electrical conductivity and concentration has been proposed [4]. In this technique, corrosion and polarization of the electrode surface will affect the accuracy of measurement and will taint the DEF solution resulting in unwanted byproducts in the exhaust. A prototype of ultrasound measurement system with electronics for measurement of DEF quality in terms of time of flight and frequency has been developed [5]. An optical method based on differential interferometry in a regularly spaced microarray is proposed for DEF quality measurement and the variation in refractive index for urea solution is reported [6]. A refractive index based hand-held device for DEF quality measurement is developed by MISCO [7]. Based on silver mirror reaction method, a fiber optic sensor applied for liquid concentration measurement has been proposed and experimentally

* Corresponding author.
E-mail address: guma@nitt.edu (U. Gandhi).

https://doi.org/10.1016/j.ijleo.2017.11.025
0030-4026/

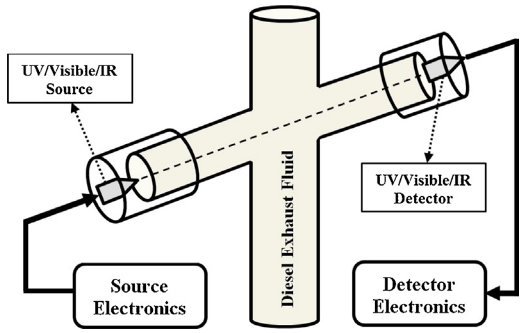

Fig. 1. Schematic of the optical based DEF concentration measurement system.

validated for glycerol solutions of different concentrations [8]. In several earlier studies, the optical methods presented for concentration measurement involves standard equipment like spectrophotometer or optical fibers which makes the measurement system occupy more space and costlier. Moreover, in majority of the measurement systems designed, attempts have been made only to present the change in refractive index and diffraction of laser over a range of concentration but the resolution required for a specific application is not considered as a design factor.

The urea concentration in DEF must be maintained at 32.5% with a tolerance of ±1.5% for the efficient operation of urea-SCR system. The storage and operating temperature significantly influences the concentration of urea. Several manufacturers have stated that the shelf life of DEF is 2 years if the temperature is maintained between 25 °C and 32 °C and it reduces to 6 months if the temperature varies between −11 °C and 32 °C. The freezing point of DEF is −11 °C and has a density of 1.093 g/cm3 at 20 °C. To ensure NO_X reduction efficiency and to protect SCR system, the DEF quality has to be continuously monitored as it is affected by temperature and other environmental conditions like presence of dust particles, etc.

In this work, an optical measurement system is designed to measure the urea concentration in DEF with 1% resolution. The proposed measurement system is compact and does not require optical fibers or spectrophotometers like the existing optical based measurement systems. The optical based measurement system operating at UV, visible and IR spectrum is proposed. An UV source, IR source and visible light source are used along with their respective detectors. The output voltage corresponds to the amount of light absorbed by the fluid medium which depends on the concentration of the medium. The proposed measurement methods in this paper are new in diesel exhaust fluid quality measurement as compared to the available methods. Further, the contribution of this work towards DEF quality measurement includes the calculation of molar absorptivity constant for various urea solutions. The absorbance spectrum of the urea solution at various concentrations using standard UV–visible-NIR spectrophotometer is also reported.

2. Measurement system principle and theory

The schematic of the optical concentration measurement system for urea in diesel exhaust fluid is shown in Fig. 1. The measurement system consists of a plus-shaped sample holder made of glass material. The optical source (UV, visible and N-IR) is fixed at one arm of the holder and the corresponding detector is placed at other end of the arm. The optical length (l) is 12.5 cm and diameter is 2 cm.

The light beam produced by the optical source propagates through the diesel exhaust fluid medium and is received by the corresponding optical detector. Light absorbed by the medium increases with increase in concentration of the medium. The Beer-Lambert's law represents the linear relationship between absorbance (A), concentration of the medium (c) and length of the medium (l) and is given by [9],

$$A = \varepsilon lc \tag{1}$$

where, ε is molar absorptivity ($mol^{-1}\,cm^{-1}\,L$), c is urea concentration in DEF ($L^{-1}\,mol$) and l is optical path length (cm).

3. Experimentation

The prototype of the measurement system along with optical source and detector electronics is shown in Fig. 2. In the detector electronics, the output voltage is measured across the load resistor instead of the detector. As the urea concentration of the medium increases the light absorbed will also increase thereby reducing the voltage drop across the detector. But as the urea concentration increases the voltage drop across the load resistor also increases. The measurement system is tested for the urea concentration variation from 0% to 40%. The three types of source-detector pair used and the wavelength range for each region are given below:

1. UV source : 190 nm–380 nm
2. Visible light Source: 380 n –700 nm