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Technical note

# Quantification of photocatalytic oxygenation of human blood

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ABSTRACT

Photocatalytic oxygenation of human blood is an emerging concept based on the principle of photocatalytic splitting of water into oxygen and hydrogen. This communication reports: (i) a design of a photocatalytic cell (PC) that separates the blood from UV (incident) radiation source, (ii) a pH, temperature and flow controlled circuit designed for quantifying the oxygenation of human blood by photocatalysis and (iii) measuring the current efficacy of ITO/$TiO_2$ nano thin films in oxygenating human blood in a dynamic circuit in real time. The average increase in oxygen saturation was around 5% above baseline compared to control ($p < 0.0005$). We believe this is one of the first attempts to quantify photocatalytic oxygenation of human blood under controlled conditions.



## 1. Introduction

The alveolar capillary membrane is the sole interface for gas exchange in humans. Tissue hypoxia occurs in many diseases and can be acute (e.g. ALI/ARDS) or chronic e.g. COPD.

Although ventilator and ECMO therapy have made an impact, there still remains vast scope for improvement in both mortality and morbidity.

Photocatalytic oxygenation of human blood is an emerging concept based on the principle of photocatalytic splitting of water into oxygen and hydrogen. The photocatalyst is a metal oxide thin film. The water content of plasma will be the source of oxygen. In theory this principle has three major advantages: (i) will oxygenate tissues even in the face of complete alveolar capillary membrane failure, (ii) can work as long as a source of light energy is available and (iii) an absence of interface between oxygen and hemoglobin molecules.

The quantification of oxygen efficacy by photocatalysis (in a real time pH and temperature controlled dynamic circuit designed to eliminate any contamination from atmospheric oxygen and errors due to sampling) is presented for the first time. This is all the more important given that the current efficacy of oxygen production with this technology is low.

The object of this paper is three fold.

Firstly to describe a photocatalytic cell that separates the blood from the UV source. Secondly to describe a circuit that can be used as a standard to quantify blood oxygenation by photocatalysis. Thirdly to measure the current efficacy of $TiO_2$/ITO nano thin films in oxygenating human blood in a dynamic circuit in real time. The average increase in oxygen saturation was around 5% above baseline compared to control ($p < 0.0005$).

## 2. Methods

### 2.1. Description of the thin film catalyst

The photo-catalyst employed in this investigation is a thin film consisting of tin doped indium oxide (ITO) and anatase $TiO_2$ (of thicknesses 75 nm and 500 nm respectively). These thin films are prepared at room temperature (300 K) by conventional reactive DC magnetron sputtering technique (using metallic targets) and are subsequently annealed at 870 K for 60 min.

### 2.2. Description of the photocatalytic (PC) cell

The prototype photocatalytic (PC) reactor (Fig. 1) consists of a hollow quartz tube (length 250 mm and diameter of 22 mm and thickness of 1 mm and outer surface area of 175 $cm^2$); blood flows on the PC surface at a rate of 1.5 l/min. A UV lamp of wavelength 254 nm (6 W) (Sankyo Denki, Japan) inserted into the tube such that the UV light enters the PC reactor through the quartz tube inner surface (blood is separated from the UV source by the quartz tube containing the thin film layer). The photon flux

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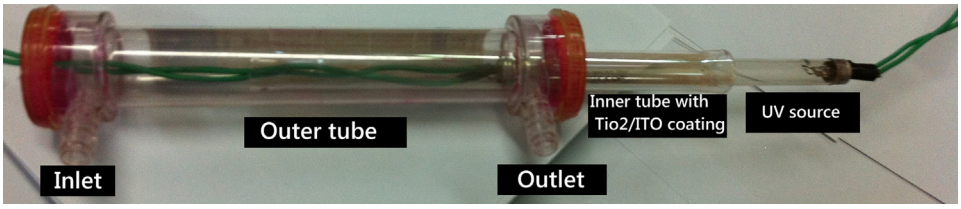


**Fig. 1.** Prototype photocatalytic cell – components.

transmitted from the outer surface of the uncoated quartz tube [as measured by a flux meter (Thorlabs PM100A, Dachau, Germany) is $19.08 \times 10^{15}$ photons/cm$^2$/s and for a photocatalytic surface, the value is $9.09 \times 10^{15}$ photons/cm$^2$/s. Thus, $1 \times 10^{16}$ photons/cm$^2$/s are absorbed by the catalyst]. This PC coated quartz tube is enclosed in a polymer casing (a F5 renal dialyser (Fresenius Kabi, Germany) that has been modified by coring out the fibers) and has been provided with air-tight inlet and outlet connectors. The volume of the reactor is 175 ml.

### 2.3. Description of the circuit

The schematic (Fig. 2) represents the circuit. It has a reservoir, a centrifugal blood pump (MC3, Ann Arbor, MI, US), a gas exchanger (050515, Sorin, US) (to add oxygen or nitrogen and control the degree of oxygenation of blood), and the PC cell (authors design) with UV source (254 nm. Sankyo Denki, Japan), a heat exchanger (CHN001821, SARNS Inc., US).

The circuit has online ultrasonic flow probe (ml/min) (MC3, Ann Arbor, MI, US), pH and temperature probes (Eutech, Thermoscientific, US) and real time measure of oxygen saturated hemoglobin and haematocrit (Hct) (CDI$^{TM}$ 101, Terumo, US).

### 2.4. Experimental procedure

#### 2.4.1. Step 1. Establishing the baseline circuit

The laboratory atmospheric pressure (Fortins barometer, K181, Watford, UK), humidity and temperature (Scientific Instruments, Roorkee, India) were measured. The standard laboratory conditions were determined during each experiment.

The circuit was primed with normal saline (volume = 800 ml). A meticulous deairing of the circuit (around 30 min) was done. Packed red blood cells (pRBCs) 250 ml was then added along with 2 ml Heparin. The total volume was 1052 ml. The pH, temperature and CDI monitors were switched on. The pH was corrected using THAM (31 ml (0.3 M solution) (Hospira) for every 250 ml of blood). The blood used was earmarked for discarding as the shelf life had expired or was obtained from patients who had had a therapeutic bleed. The safe disposal of blood used was mandated by the IIT committee and the responsibility was undertaken by the Department of Biotechnology IIT-Madras.

#### 2.4.2. Step 2. Ensuring stored blood had retained oxygen carrying capacity

Oxygenation of blood with external oxygen is done through the membrane oxygenator in order to establish that the stored blood still retained its oxygen carrying capacity. This is established by ensuring that 100% saturation is attained before each experiment. Blood that was lysed or was not able to saturate to 100% was discarded.

#### 2.4.3. Step 3. Deoxygenation of blood

Nitrogen was passed through the gas exchanger until the $SO_2$ was 73.3% (range 69–79).

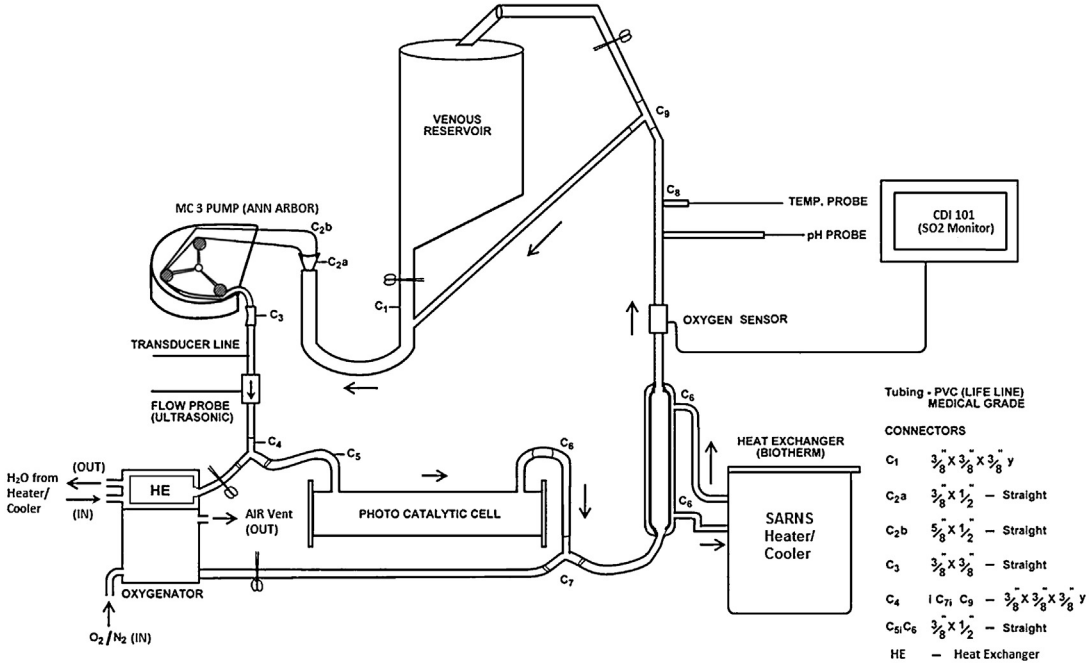


**Fig. 2.** Schematic of the prototype circuit used to quantify photocatalytic oxygenation.