A Flexible Smart Wound Dressing with Integrated On-Demand Oxygen-Release and Sensing Capability

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ABSTRACT

A lab-based flexible smart wound dressing with integrated on-demand oxygen delivery and sensing system has been successfully developed. This dressing is fabricated on a biocompatible hydrophobic parchment paper substrate that incorporates patterned catalytic oxygen generating regions and an array of oxygen sensors. The oxygen is generated by flowing hydrogen peroxide over inkjet printed MnO_2 catalyst on the parchment paper. The hydrogen peroxide is delivered/guided to the printed catalyst regions through a network of low-profile and flexible microfluidic channels that are bonded to the parchment paper and the flow is controlled by an electronic module. The oxygen sensor is developed by inkjet printing oxygen sensitive ruthenium dye on the parchment paper. The wound-facing side of the smart dressing features a biodegradable matrix (Integra or PriMatrix wound matrix) that is bonded to the parchment paper with fibrin glue and permits oxygen exchange between the sensors/generators and the wound bed. The test results of inkjet printed oxygen generation and sensing samples demonstrated the capability of employing the dressing for the treatments of chronic wound applications.

INTRODUCTION

- Suboptimal oxygenation of the wound bed is a major healing inhibitor in chronic wounds. Unlike acute injuries that receive sufficient oxygen via a functional blood vessel network, chronic wounds often suffer from the lack of a proper vascular network; thus they are incapable of providing sufficient oxygen for tissue growth.
- While the lack of oxygen may trigger vascular regeneration, the severity and depth of wounds can prevent adequate regeneration, and cause wound ischemia. Modern medical treatment of hypoxic chronic wounds typically employs hyperbaric oxygen therapy, which requires bulky equipment and often exposes large areas of the body to unnecessarily elevated oxygen concentrations that can damage healthy tissue.
- A more practical approach is topical oxygen therapy (TOT) where the dressing itself can generate and deliver the required oxygen. An ideal strategy is to develop a dressing for adaptive closed-loop oxygen therapy capable of measuring the wound-bed oxygen level and deliver appropriate oxygen where and when it is needed.

OXYGEN GENERATION AND SENSING PACTHES

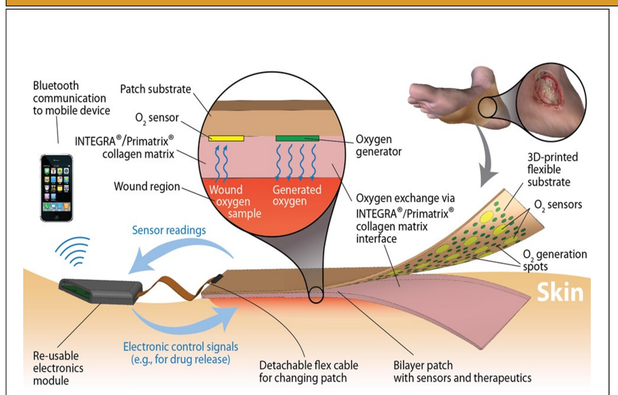
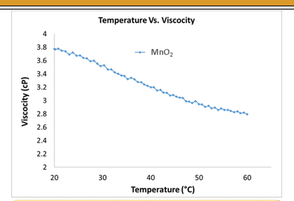
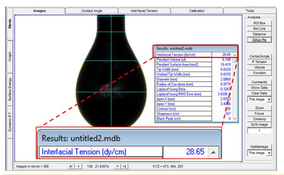


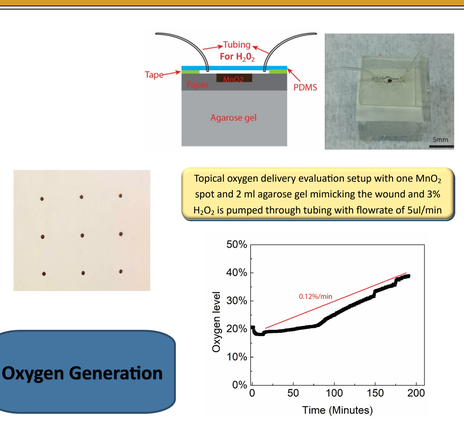
Illustration of smart oxygen generation and sensing patch



Graph showing the temperature vs viscosity of MnO_2 ink measured using AR 2000 Rheometer



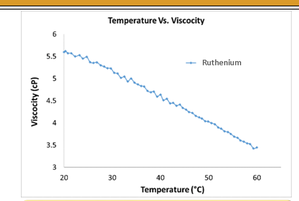
Screen shot of the FTA200 software showing the surface tension of the MnO_2 ink measured using pendant drop method



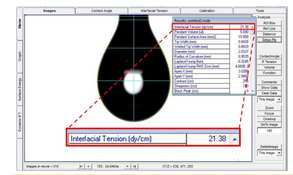
Topical oxygen delivery evaluation setup with one MnO_2 spot and 2 ml agarose gel mimicking the wound and 3% H_2O_2 is pumped through tubing with flowrate of 5ul/min

Oxygen delivery result of 1 MnO_2 spot shows 20% increase in oxygen level within 165 min at the rate of 0.12%/min

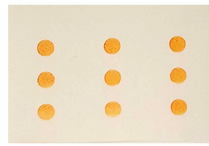
Oxygen Generation



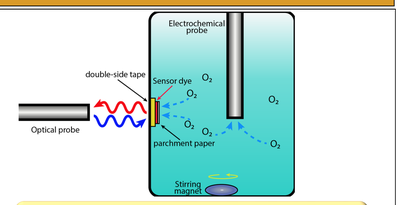
Graph showing the temperature vs viscosity of Ru ink measured using AR 2000 Rheometer



Screen shot of the FTA200 software showing the surface tension of the Ru ink measured using pendant drop method



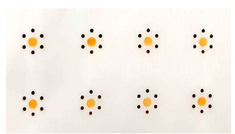
Oxygen Sensing



Experiment setup for testing one oxygen sensitive Ru dye with an optical probe for measuring fluorescence lifetime decay of dye and electrochemical sensor to measure various dissolved oxygen concentration in the water

Oxygen sensing result showing the fluorescent life time decay of 1.091 µsec of one Ru dye up to atmospheric oxygen level of 21% (9 mg/L)

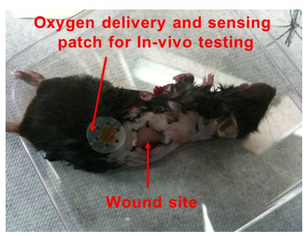
SMART DRESSING INTEGRATION AND IN-VIVO TESTS



Printed unit cell patch array with ruthenium and MnO_2 spots for in-vivo tests

Scalable massive fabrication for patch arrays

A fully developed smart dressing patch attached to a hand mannequin



Oxygen delivery and sensing patch for in-vivo tests on rats

CHEMICAL (HYDROGEN PEROXIDE) DELIVERY SYSTEM

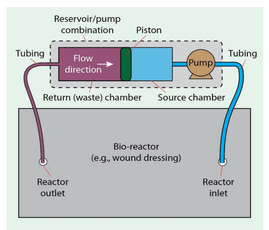
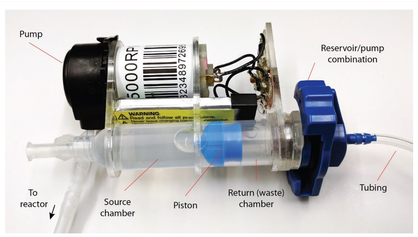
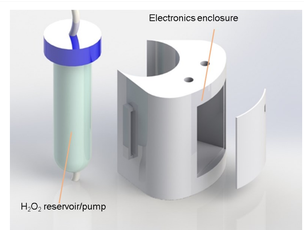


Illustration of a closed-loop chemical (H_2O_2) delivery system



Prototype of chemical (H_2O_2) delivery system



A compact 3D design of reservoir tube and electronics enclosure to give patients more convenience and easier access to electronics as well as battery

CONCLUSION AND FUTURE WORK

- A lab-based smart wound dressing consisting of a biocompatible hydrophobic parchment paper substrate incorporating patterned catalytic oxygen generating regions and an array of oxygen sensors was successfully fabricated.
- The inkjet printed single layer MnO_2 catalyst spot of 1 mm diameter on the parchment paper shows a 20% increase in oxygen level within 165 minutes at the rate of 0.12%/min when 3% H_2O_2 is pumped through tubing with flowrate of 5ul/min. The inkjet printed single layer ruthenium dye of 5 mm diameter on the parchment paper shows a fluorescent life time decay of 1.091 µsec for the dissolved oxygen level up to 21% (9mg/L).
- The experiment results of a low cost, single platform, inkjet printed, flexible oxygen generation and sensing dyes successfully demonstrated the capability of employing the patches as smart dressings for the treatments of chronic wound applications.
- Currently, cytotoxicity and in-vivo tests are being carried out on the fabricated smart wound healing patches at Indiana University School of Medicine by Dr. Michael Zieger. Also, an alternative compact embodiment that uses a more compact pump for H_2O_2 delivery to the catalyst spots is being developed.

ACKNOWLEDGEMENTS

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