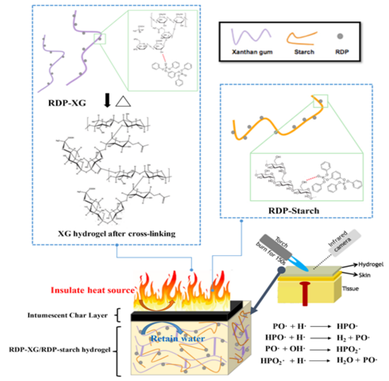
Stony Brook University

Synthesis of A Novel Flame-retardant Hydrogel for Skin Protection Using Xanthan Gum and Resorcinol Bis(diphenyl phosphate)-coated Starch

Bole Pan [1,a], Mingkang Li [2,a], Yuan Xue [3], Miriam Rafailovich [3*]

[1] Guangzhou Tianhe Foreign Language School, Guangzhou 510627, China; [2] Shanghai Star-river Bilingual School, Shanghai 201108, China;
[3] Department of Materials Science and Engineering, Stony Brook University, NY 11794, USA; [a] These authors contributed equally to this work

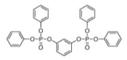
Introduction



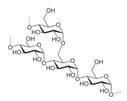
- **Firefighters continually endanger their lives in order to rescue others**
  - In 2017 alone, 2,835 U.S. firefighters suffered from burn-related injuries
- **Current protective equipment for firefighters**:
  - Cannot provide effective protection for faces
  - Unable to withstand prolonged flame exposure
- **Hydrogel:** a cross-linked network of polymer chains in which water is the dispersion medium.
- Developing a flame retardant hydrogel for skin protection would greatly reduce these risks.
- Here, we present the synthesis of said hydrogel using all biodegradable and non-toxic materials.

Materials and Methods

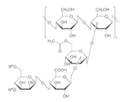
- **Resorcinol bis (diphenyl phosphate) (RDP)**
  - Alternative to Halogenated compounds
  - Identified by EPA as having minimal toxicity.
  - Acid precursor: Promotes charring
  - High mobility - need substrate



- **Starch**
  - Thermally stable
  - Inexpensive and easily available
  - Charring ability



- **Xanthan gum (XG)**
  - Widely used in food industry
  - Ideal cross-linking agent

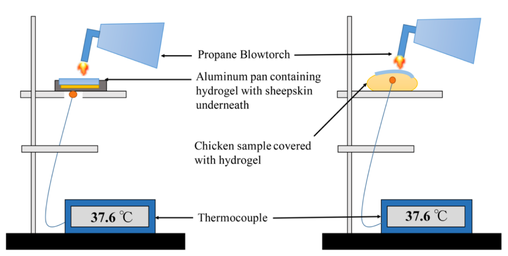


➔ **12 Samples**

Sample	XG(wt.%)	RDP-coated XG(wt.%)	RDP-coated Starch(wt.%)
1XG	1	0	10
1XG10RDP-starch	1	0	10
2XG	2	0	10
2XG10RDP-starch	2	0	10
2.5XG	2.5	0	10
2.5XG10RDP-starch	2.5	0	10
1RDP-XG	0	1	10
1RDP-XG10RDP-starch	0	1	10
2RDP-XG	0	2	10
2RDP-XG10RDP-starch	0	2	10
2.5RDP-XG	0	2.5	10
2.5RDP-XG10RDP-starch	0	2.5	10

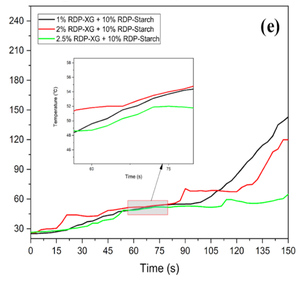
Flammability Assessments

Setup:



Section 1: On Sheepskin

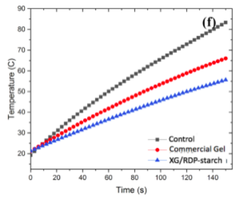
- 2.5% wt. RDP-XG + 10% RDP-coated starch had the optimal performance
- Remained below 45 °C for 50 seconds and below 55 °C for 114 seconds
- Outperformed a commercial FR by 30% in terms of final temperature

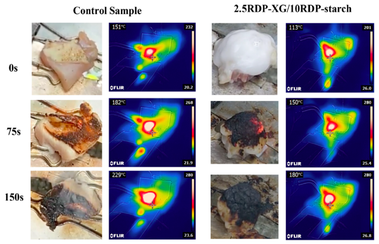


- Char layer formed after burning for 150 seconds

- Sheepskin remains after burning for 150 seconds

Section 2: On Chicken Skin





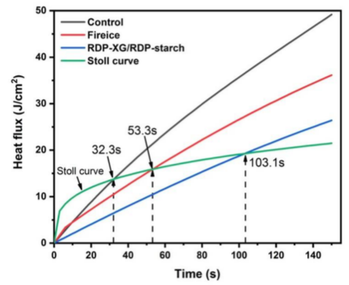
Final Bottom Temperature
RDP-XG/RDP-Starch: 55°C
Commercial Product: 65°C
Control: 83°C

●well-preserved under the char layer

$$Q(J/cm^2) = \frac{m \times C \times (T_{final} - T_{initial})}{A}$$

$$Stoll\ curve\ (J/cm^2) = 5.0204 \times t_i^{0.2901}.$$

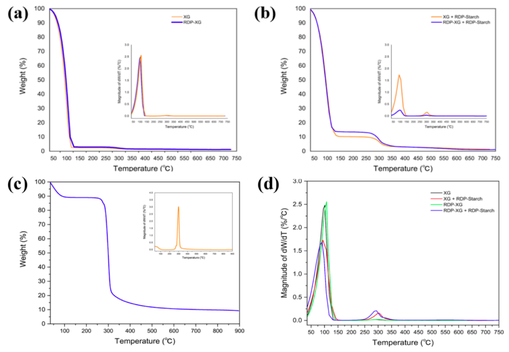
- Skin-protection time before receiving second-degree burn:
  1. This work: 103 s
  2. Commercial product: 21s
  (Outperformed by 93.4 %)



Characterizations

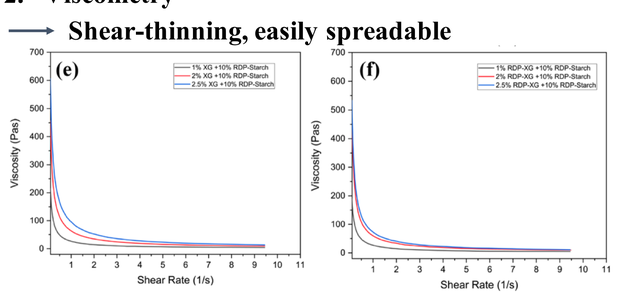
1. Thermal Gravimeteric Analysis (TGA)

➔ **Thermally stable: No toxic volatile at low temp.**



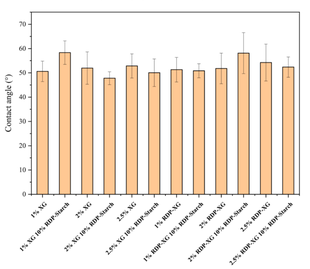
2. Viscometry

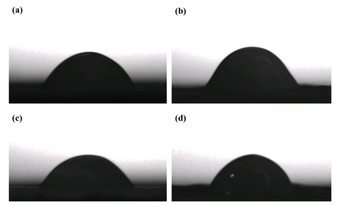
➔ **Shear-thinning, easily spreadable**



3. Goniometry

➔ **Adhesive to skin**

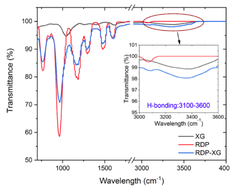




a) 2.5XG/10RDP-starch;
b) 2.5RDP-XG/10RDP-starch; c)2.5XG;
d) 2RDP-XG/10RDP-starch

4. FTIR Spectra

➔ **Hydrogen bonding presence**

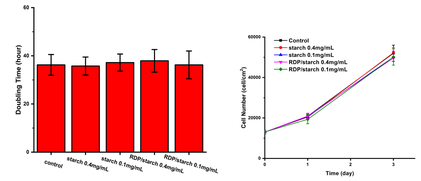


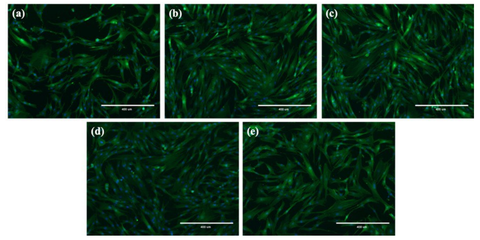
5. pH tests

➔ **pH ≈ 6, no skin irritation**

Toxicity Test

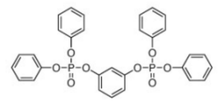
- No difference in doubling time with control
- Non toxic





Mechanisms

Gas Phase: Radical reactions slow down oxidation of hydrocarbons



Resorcinol
Bis(diphenyl phosphate)

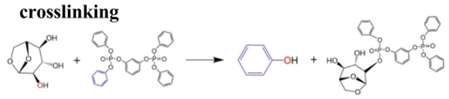
heating

$PO\cdot + OH\cdot = HPO_2$
$HPO + H\cdot = H_2 + PO\cdot$
$OH + OH\cdot = HPO_2\cdot$
$HPO_2\cdot + H\cdot = H_2O + PO\cdot$
$OH\cdot + H_2 + PO\cdot = H_2O + HPO$
$HPO_2\cdot + H\cdot = H_2O + PO$
$HPO_2\cdot + H\cdot = H_2 + PO_2$
$HPO_2\cdot + OH\cdot = H_2O + PO_2\cdot$

Condensed Phase: Endothermic formation of Char Layer

RDP

Promotes charring through transesterification and crosslinking



Promotes charring through dehydration (RDP decomposes into phosphoric and polyphosphoric acid upon heating)

Summary

We have synthesized an anti-burn hydrogel that
- ➢ Incorporates an IFR System
- ➢ Uses all biodegradable, non-toxic materials
- ➢ Thermally stable, spreadable, adhesive
- ➢ Exhibits excellent flame-retardancy, skin protection time 103 s

Acknowledgements

- This research was supported the Louis Morin Charitable Trust and NYS Department of Economic Development