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Spray-on cellulose based thermal insulation foams

”Development of cellulosic in-situ spray-on materials”

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Content

1. Background
2. Aim of work in WoTIM project
3. Highlights from results of other research groups
4. Work in WoTIM project
   - Challenges
   - Researched issues
   - Raw materials
   - Test methods
   - Results
5. Conclusions

Background

Foamed plastic insulation materials are oil-based and therefore not ecologically sustainable materials.

The used spraying chemicals for foamed polyisocyanurate and polyurethane (PUR) are hazardous for health before curing has occurred. Also during a fire PUR will release hydrogen cyanide and isocyanates, which are very poisonous.

Although many types of cellulose fibre based thermal insulation materials exist, none of them forms a closed foam structure and can be sprayed into wall cavities.

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Aim of the work in WoTIM

Our aim:

- to investigate and explore the possibilities to create a new wood-based cellulosic in-situ spray-on thermal insulation foam to replace traditional spray-on plastics insulation foams on construction site

- main material of the foam is wood fibres and/or fibrils
- additives preferably also wood based chemicals, harmless to human and environment
- a laboratory scale proof of concept

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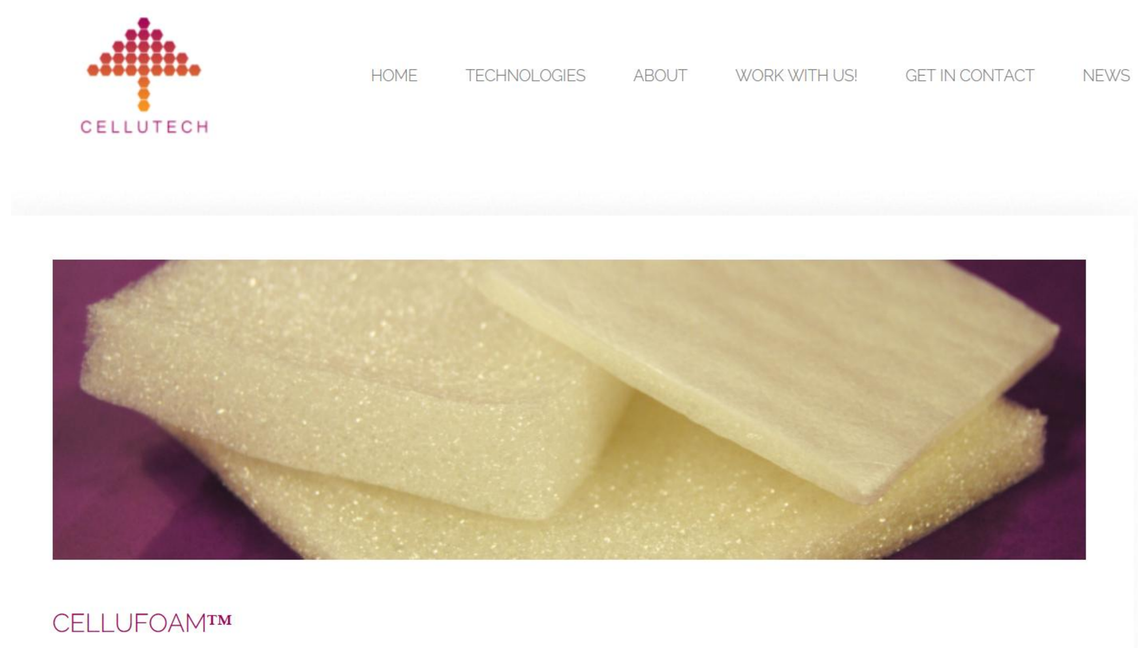
Highlights from research results of others

Cervin N.T., Andersson L., Ng J.B.S., Olin P., Bergström L., and Wågberg L., *Lightweight and Strong Cellulose Materials Made from Aqueous Foams Stabilized by Nanofibrillated Cellulose,* Biomacromolecules 2013, 14, 503−511

- A lightweight and strong porous cellulose material has been prepared by drying aqueous foams stabilized with surface-modified nanofibrillated cellulose (NFC).
- similar to the Pickering emulsion technique, but the nonpolar phase in this case is air. Material: NFC + octylamine.
- cellulosebased material with a porosity of 98% and a density of 30 mg cm−3. Most pores are in the range of 300 to 500 µm.

→ Excellent dry foam. Closed cells can be obtained. However, the needed drying process is not suitable for on-site solutions (need for filtration, wet foam rheology and sticking properties etc.)

→ CelluTech utilises the patent



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Highlights from

Cervin et al., continued

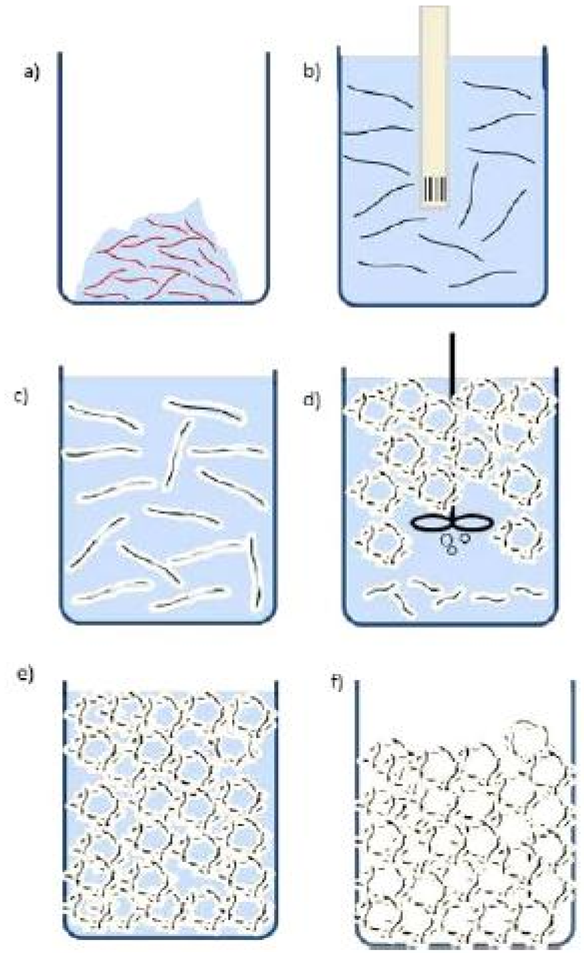

Figure 1. Schematic description of the different steps for the preparation of NFC-stabilized foams: (a) NFC-gel (2 wt % in aqueous solution); (b) octylamine mixed with the NFC-gel in an Ultra Turrax mixer; (c) octylamine attaches to the NFC due to electrostatic adsorption; (d) air bubbles are created by a beater and covered with the modified NFC; (e) aqueous foam stabilized by NFC; (f) the wet foam is dried at ambient conditions and a porous cellulose material is formed, as shown in Figure 2.

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Highlights from research results of others

Energy Design Update, May 1, 2015, 6:
The researchers at the Fraunhofer Institute for Wood Research adopted a very promising approach to the problem by developing a method for creating foam from wood particles.

- The scientists produce the foam by grinding wood very finely until the tiny wood particles become a slimy mass. They then add gas to this suspension to expand it into a frothy foam, that is then hardened. The hardening process is aided by wood based substances.

"It's a bit like baking, when the dough rises and becomes firm in the oven," Professor Thole explains. The resulting wood foam is a lightweight base material that can then be made into rigid foam boards and flexible foam mats.

→ Method not suitable for in-situ spray-on.

Samples of Fraunhofer's wood foam insulation

http://newatlas.com/wood-foam-insulation/31133/

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Highlights from research results of others

Novel aqueous spongy foams made of three-dimensionally dispersed wood-fiber: entrapment and stabilization with NFC/MFC within capillary foams

Liu, Yang; Lu, Peng; Xiao, Huining; Cellulose, 10/2016

First published 28.10.2016

- The main focus was to create a novel ultra-lightweight, highly microporous foam reinforced with MFC or nanofibre to enhance the compressional strength in vertical direction.
- The stability of spongy foams could be controlled by manipulating the volume fraction of NFC and/or MFC and a secondary liquid immiscible with the continuous phase of the NFC and/or MFC suspension
- Agar was chosen as the second liquid to retain bubbles, according to the “gel trapping technique”
- Flocking agent, CPAM → counter-charge bridge mechanism

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Highlights from research results of others

Liu, Yang; Lu, Peng; Xiao, Huining; Cellulose, 10/2016, continued

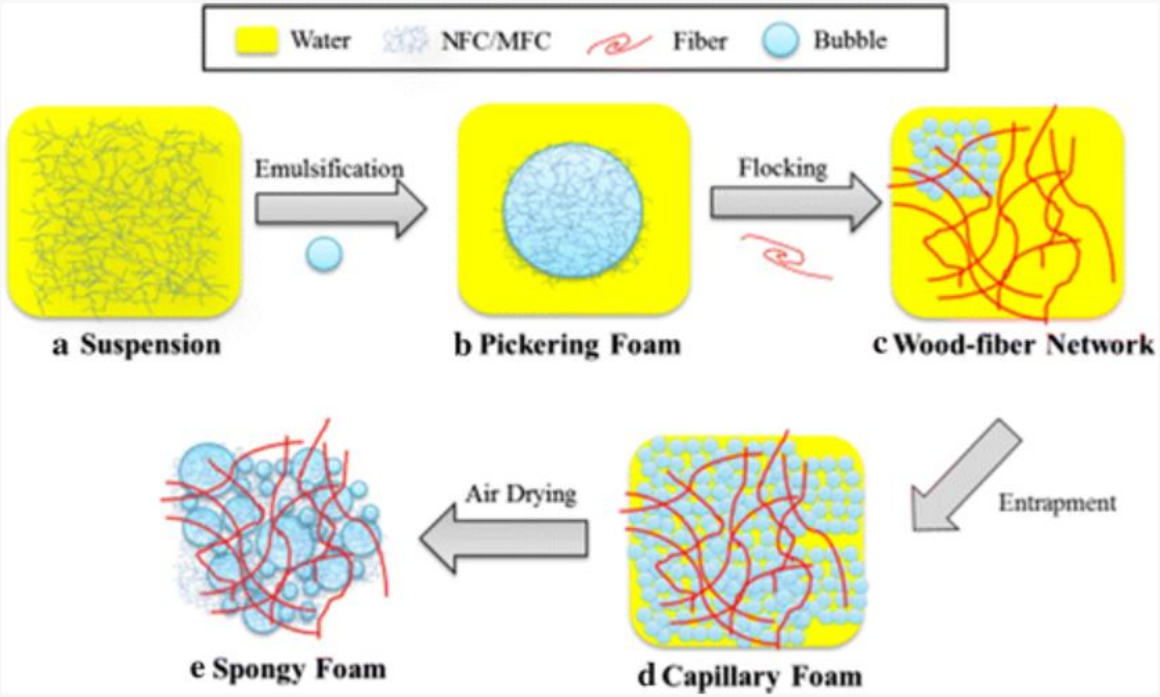

Fig. 3

Schematics of preparation of 3D spongy foams. **a** NFC and/or MFC suspensions are the starting point. **b** Suspension mixing with a predetermined amount of SDS can result in PFB of A/W stabilized with NFC and/or MFC particles. **c** Mixing with a small amount of cPAM can result in the flocking of three-dimensional cage matrix. **d**Entrapment of NFC and/or MFC pickering foam bubbles can formation of wood-fiber wet foam. **e** Air or oven drying (40–60 °C) overnight can obtain wood-fiber solid foams

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Aim of the work in WoTIM

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Challenges when using in-situ spray-on cellulose foams

1. Water issues – water based foams
   - Ø Shrinking in drying → loosing insulation ability
   - Ø Too slow drying
2. Material has to stick to surfaces and form uniform bulk structure (no splits)
3. From open cells to closed cells → better insulation and wind proof (low air permeability)
4. Portable foam producing and spraying equipment

Raw materials

Fibre materials from pulp to nanofibrillated cellulose

- bleached softwood kraft pulp
- refined birch pulp, SR 85-90
- fibrous material, size 'fines', 100-200 mesh = 75-150 mm (FCBA)
- enzymatically fibrillated pulp, size is microfibrillated cellulose, MFC
- microfibrillated cellulose, pressure 500 bar (FCBA)
- microfibrillated cellulose, pressure 1000 bar (FCBA)
- nanofibrillated cellulose, CNF (Innventia)

Researched and tested issues

1. Foam stabilizers
2. Improving foam adhesion to surfaces
3. Contributing to closed pore formation
4. Prevention of shrink
5. Screening foaming and spraying equipment
6. Decreasing the water content of the insulation foams
   - dessicants
   - raising dry content before foaming

- amount (and ionic properties) of surfactant
- adding water soluble polymer (cellulose derivatives, PVA, etc.)
- nanocellulose, micro fibrillated cellulose
- cellulose derivative
- crosslinker (polycarboxylic acid)
- cationic hydrophobic additives

Test methods

Foaming equipment

- speed mixer
- kitchen mixer
- pressurized whipper

Visual evaluation

- collapsed/not collapsed
- shrinking
- sticking to surfaces
- splits and cracks

Drying of foams

- in window slit at room temperature
- in mold at room temperature
- in mold in oven (50 °C)

Microscopic analysis (only of some foams)

- wet foams
- dry foams

Air flow resistance (measurements only for some foams)

Results- Main material pulp

Main material pulp: We have established a method to produce fibre foams which shrink only slightly (<10%) during drying. The foam sticks excellently to wooden, metal and concrete surfaces and to painted surfaces.

However: The material was considered too rough to the intended purposes and this research line was discontinued.

Figure: Pulp based dry foam. Density 0,07 g/cm^3 (density of cellulose 1,5 g/cm^3).

Results - Main material nanofibrillated cellulose, microfibrillated cellulose or pulp fines

By using the title materials, we were not able to establish a concept to produce fibre foams with desired qualities. Foams collapsed in drying, although several additives and foam contents were tested.

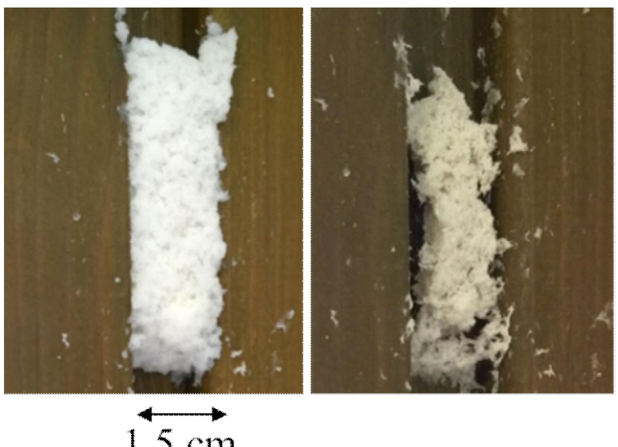

Figure: Microfibrillated cellulose from FCBA + grinded pulp (1:1) + additives. Wet and dry foam in the window slit. Dry content of the water based paste was 11% (w/w). Air content of wet foam 50 %.

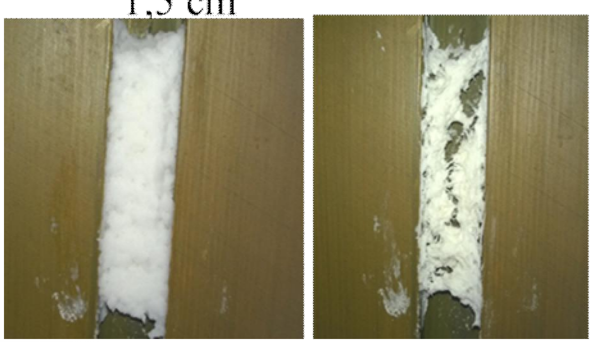

Figure: Enzymatically fibrillated cellulose + grinded pulp (1:1) + additives. Wet and dry foam in the window slit. Dry content of the water based paste was 13% (w/w). Air content of wet foam 30 %.

Results - Main material refined pulp

Main material refined pulp, SR85-90: We have established a method to produce fibre foams which although shrink somewhat (10-20%) during drying, still stick tightly to the frame and keep the uniform bulk structure. However, thinning of the layer in the middle occurs. The foam sticks excellently to wooden, metal and concrete surfaces and to painted surfaces.

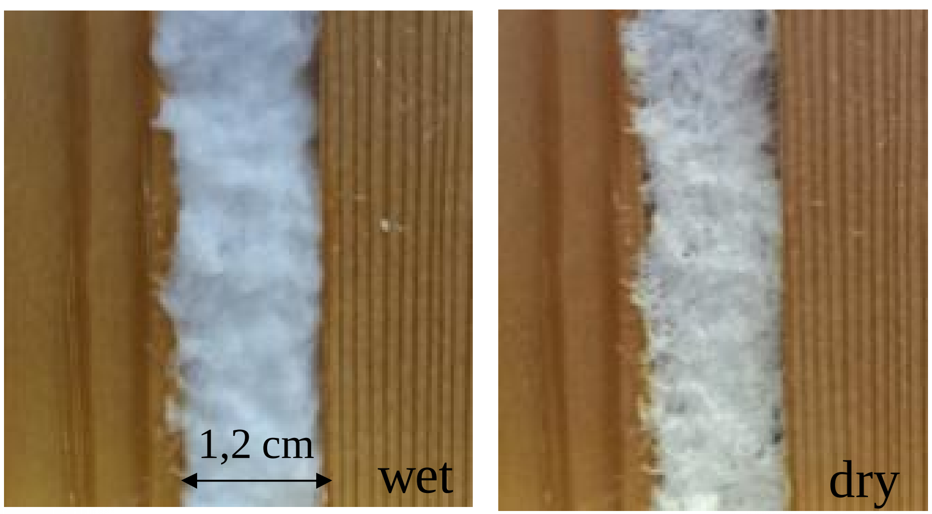

Figure: Refined pulp (SR 89) based wet and dry foam in the test window slit.
Dry content of water based paste was 12% (w/w). Air was introduced by speed mixer to the paste, volume of air was adjusted to ~50 %.

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Foam producing and on-site spraying equipment screening

- Mechanical mixing of gas (air) into solution + pumping the foam to nozzle and spraying
  - Possible, separate equipment exists for small scale mixing, and for pumping the foam through nozzle
- **Injection of gas in high pressure and then reducing pressure by spraying**
  - Probably the easiest solution
- Formation of gas by chemical reaction
  - Difficult, we did not find existing concepts

Video: Grinded pulp is foamed in-situ and sprayed to the window slit

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Conclusions

- There is not ready solutions for wood fibre material to be sprayed into wall cavities to form closed foam structure.
- Solution developed in WoTIM project is very promising, but not yet ready to upscaling. Further development is needed:
  - Dry content of material should be raised; drying time in window slit is two to three days. Blowing of warm air (50°C) shortens the drying (to only some hours).
  - Amounts and charge properties of additives need more optimisation.
  - Shrinking and spliting to layers was not totally avoided. They could be avoided by introducing MFC to fiber network utilizing the method of Liu et al.
  - Equipment / machinery producers are needed to the next stage of the development work