From Nanocellulose Science towards Applications
Status up-date from Finland

Presented by:
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Agenda

- What is Nanocellulose?
- Where is can be used? – Based on Structure-Properties Relationships
- Towards Applications? – Based on public research results
- Application studies by Industry
- Standardization
Nanocellulose research in Finland
A wood-based nanomaterial: nanocellulose

Unique properties
- Mechanical
- Optical
- Surface area

Physical dimensions
- Diameters: ~10-100nm
- Lengths: ~100 nm–100 µm
- Different surface functionalities

Nanocelluloses – A Class of Nanomaterials

- Examples of Raw Materials:
  - Wood
  - Pulp
  - Bacteria
  - Straw
  - Sugar Beet
  - Banana

- Examples of Production Methods:
  - Grinding, Homogenizer, Intensification, Hydrolysis / Electrospinning, Ionic liquids

- Hans-Peter Hentze, VTT - ‘From Nanocellulose Science towards Applications’ - 2nd of June 2010 -
Suitable characterization methods depend on fibril type

Sneck, A., 2011 TAPPI International Conference on Nanotechnology for Renewable Materials

**Size/Dimensions/Branching**

**Chain or rod-like structure**
All dimensions in nanoscale

- CNC, Nanocrystals
- CNF, Nanofibers

**Ribbon-like structure**
Overall dimensions in macroscale, fine structure in nanoscale

**Branched structure**
Overall dimensions in macroscale, fine structure in nanoscale

**Charge/mass**

- Colloidal dispersion
- Polyelectrolyte-like

**Wood-fibre like**
Decreasing surface charge

Scale bar: 20 μm
NFC grades vs. commercial MFC
Optical microscope images, macrostructure

Masscolloider
Fluidizer
Commercial MFC 1

Carboxymethylation
TEMPO
Commercial MFC 2

Tiina Pöhler et al, 2010 TAPPI International Conference on Nanotechnology for the Forest Product Industry
Manual analysis of FE-SEM images: dry fibril width

Fluidizer

Carboxymethylation

• Similar information than with AFM

Tiina Pöhler et al, 2010 TAPPI International Conference on Nanotechnology for the Forest Product Industry
Nanocellulose application research in Finland
Potential application areas based on specific advantages of nanocellulose

Properties of nanocellulose
- Natural & renewable
- Biodegradability
- Biocompatibility
- High strength & modulus
- High surface area
- High aspect ratio
- Chemical functionality (e.g. for modification)
- Dimensional stability
- Moisture absorption
- Thermal stability (~200°C)
- Others …

Potential applications
- Composites
- Construction Materials
- Porous Materials
- Fiber Web Structures (e.g. Paper & Board)
- Coatings
- Functional Surfaces
- Functional Additives (e.g. rheological modifiers)
- Others …
Porous materials & fiber web structures

- Porous nanocellulosic materials for insulation & packaging
  - Highly porous & strong nanocellulose web structures
    (e.g. Svagan *et. al*, *Advanced Materials*, 1263-1269 (2008))

X-ray microtomography:

- Applications: Cellular bioplastics, insulation and packaging, (bio)active membranes & filters

  - Hans-Peter Hentze, VTT - ‘From Nanocellulose Science towards Applications’ - 2nd of June 2010 -
Thermoplastic NFC composites

- In-situ polymerisation of NFC-g-PCL materials (<1% NFC) => Increases in melt strength and mechanical properties. Orientation further improves mechanical properties.
Porous Materials & Fiber Web Structures

- Paper & Board Strength Enhancement

Wood fiber web structures – Paper as a porous nanocomposite


NFC increased both: binding area and binding strength \( S_{\text{tot}} \sim A_B \cdot S_B \)

Applications: High strength / high bulk / high filler
A jump towards raw material and energy-efficient papers
NFC-based filler containing SC paper

CO2 eq. of 1000kg SC paper

- 2 – 4% NFC addition:
  - Filler content increased from 24% to 50%
  - 15% decrease in carbon footprint
  - 30% less drying energy
  - Good wet strength
  - Better optical properties
  - Cost saving potential

National project
New product opportunities
High filler content (80%) substrates for printed electronics applications, printed conductors

Two most essential properties:
- smoothness
- dimensional stability

Potential:
- Rapidly growing markets
- Sustainable electronics (printing with water-based inks demanding on plastics)

National project
Coatings & Functional Surfaces

- Nanocelluloses for Coating Applications
  - Nanocelluloses as barrier materials
  - Specific advantages: high oxygen barrier, affinity to wood fibers
    Disadvantage: Moisture sensitive (hydrophobic compound required)

Multilayered coating with oxygen and water vapor barrier properties

(Hult et al, Cellulose, 575-586 (2010))

- Application: Food packaging, printing papers
  (smooth surfaces, NFC as an organic pigment)

- Hans-Peter Hentze, VTT - ‘From Nanocellulose Science towards Applications’ - 2nd of June 2010
EU SUNPAP: Foam application of nanofibrillated cellulose
Thin layers 0.5-2 g/m² applied

NFC, solids content 2.98%
Foamed NFC, 90% air
NFC films

- Unmodified NFC films in dry conditions are good oxygen barriers.

- Combination of NFC with well-known barrier materials and additives (PVA and nanoclay) significantly enhance the barrier properties at high humidity.
NFC films

- Printed film of nanocellulose manufactured in pilot scale through controlled adhesion, spreading and drying of NFC with excellent smoothness without any wiremarkings.
Functional Additives

- Nanocelluloses as rheology modifiers
  - NFC as a thixotropic, biodegradable, dimensionally stable thickener (stable against temperature and salt addition)
  - Low-calories **food** applications
  - Thickener in **cosmetics**
  - **Pharma** (tablet binder, diagnostics: bioactive paper)
  - Pickering stabilizer for **emulsions** & particle stabilized **foams**
  - **Paint** formulations
  - Enhanced **oil recovery**
NFC as additives in paints and resins

- Homogeneous distribution of nanoparticles and prevention of deposition of the additives in paint and resin applications.
- NFC network acts also as rheology modifier, less sensitive to temperature changes.
“Three pillars of sustainable development” - not only economic, but also environmental and social impacts

EU SUNPAP: Risk assessment focused on NFC and occupational exposure, toxicity in vitro and in vivo

Focus

Source: Pöyry
Finnish forest companies – global frontrunners in bringing nanocellulose to business
UPM-Kymmene Ltd

**UPM** started pre-commercial production of fibril cellulose and is developing new fibril cellulose applications with industrial partners.

- Objective to create the preconditions needed for industrial-scale production of fibril cellulose.
- The first stage mainly consists of developing products used in paper and packaging materials and the concrete and paint industries.
- UPM's fibril cellulose provides new properties and design opportunities for traditional materials; it can be used to make products tougher, lighter or thinner, depending on the application. (UPM 15 November 2011)
Stora Enso Ltd

Stora Enso is building a pre-commercial plant at Imatra for the production of microfibrillated cellulose.

- New type of renewable material will be used in existing and new unique fibre-based paper and board products, barrier materials.
- With MFC it is possible to develop lighter, stronger renewable packaging materials. In the longer term, the applications of the material may well extend to replacing today's fossil-based materials such as plastics and some speciality chemicals, and aluminium. (Stora Enso 31 May 2011)
Roadmap for the Development of International Standards for Nanocellulose

Third Draft – October 10, 2011

This is a collaborative document prepared by an international community of scientists and professionals to chart the path forward in developing international standards.

Contents

1. INTRODUCTION ........................................................................................................................................... 2
   1.1. Key Goals .............................................................................................................................................. 3
   1.2. The Importance of Standards for Commercial Development ................................................................. 3
   1.3. Leveraging Existing Standards Committees for Nanomaterials ............................................................. 4
2. CRITICAL SUCCESS FACTORS FOR STANDARDS DEVELOPMENT ......................................................... 4
   2.1. Garnering Engagement from all Sectors .................................................................................................. 5
   2.2. Key Collaborative Intersections ............................................................................................................ 5
3. STANDARDS FOR CELLULOSE NANOMATERIALS ...................................................................................... 6
   3.1. Terminology and Nomenclature ............................................................................................................. 6
   3.2. Measurement and Characterization ........................................................................................................ 8
   3.3. Environment, Health and Safety .......................................................................................................... 13
   3.4. Material Specifications ......................................................................................................................... 15
4. KEY MILESTONES ..................................................................................................................................... 18
Standardization

- Roadmap work for ISO autumn 2011

- Companies in Finland started last year to measure viscosity of NFC/MFC
  - with the selected procedure that includes sample-taking, measurement, and computation and processing of results.

- Terminology discussions difficult without knowing characteristics
Multiple industrial products, consumer and well being applications
Acknowledgements

- My coworkers Pia Qvintus, Hans-Peter Hentze, Markus Linder, Ali Harlin, Tekla Tammelin, Mika Härkönen, Erkki Hellen at VTT

The research leading to these results received funding from the European Community’s Seventh Framework Programme under Grant Agreement No 228802
Thank you

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