CENTER FOR ADVANCED RESEARCH IN DRYING

A National Science Foundation Industry/University Cooperative Research Center

Experimental Study of Drying of Paper with Ultrasound Mechanism

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Sustainability Project Competition
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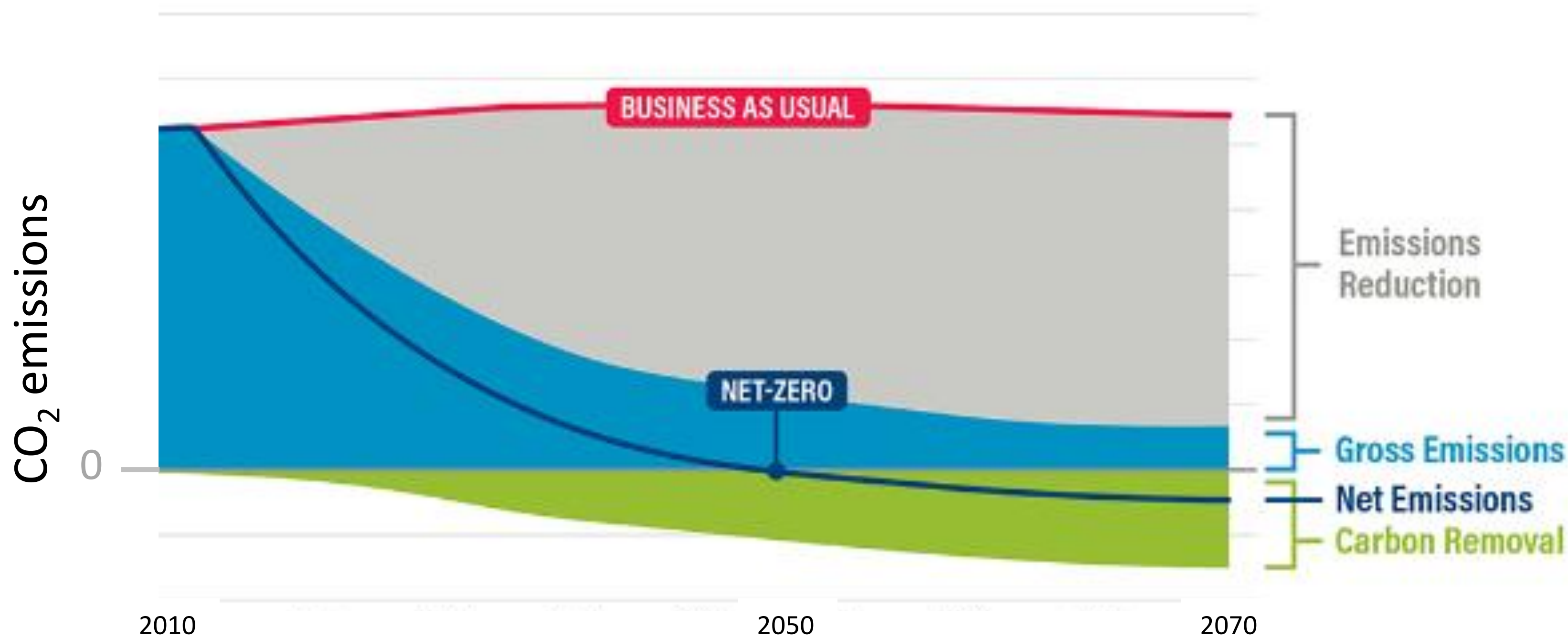
Motivation - Net Zero Carbon Footprint by 2050

- The global temperature needs to be managed (global warming).
- Industry sector is the source of 24% of greenhouse emissions in the USA.



https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#colorbox-hidden
https://www.wri.org/insights/net-zero-ghg-emissions-questions-answered

Why Is Drying Important?

Estimated energy use in common industrial processes

Process heating operation	Description/example applications	Typical temperature range (F)	Estimated (2010) U.S. energy use (TBtu)
Fluid heating, boiling, and distillation	Distillation, reforming, cracking, hydrotreating; chemicals production, food preparation	150–1000°	3,015
Drying	Water and organic compound removal	200–700°	1,178
Metal smelting and melting	Ore smelting, steelmaking, and other metals production	800–3000°	968
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Non-metal melting	Glass, ceramics, and inorganics manufacturing	1500–3000°	199
Curing and forming	Polymer production, molding, extrusion	300–2500°	109
Coking	Cokemaking for iron and steel production	700–2000°	88
Other	Preheating; catalysis, thermal oxidation, incineration, softening, and warming	200–3000°	1,049
Total			**7,204**

- Industrial drying consumes 12% of all process energy used in American manufacturing annually.

US Department of Energy, *Quadrennial Technology Review*, September 2015, Table 6.1, p. 189.

Estimated energy savings by new technologies

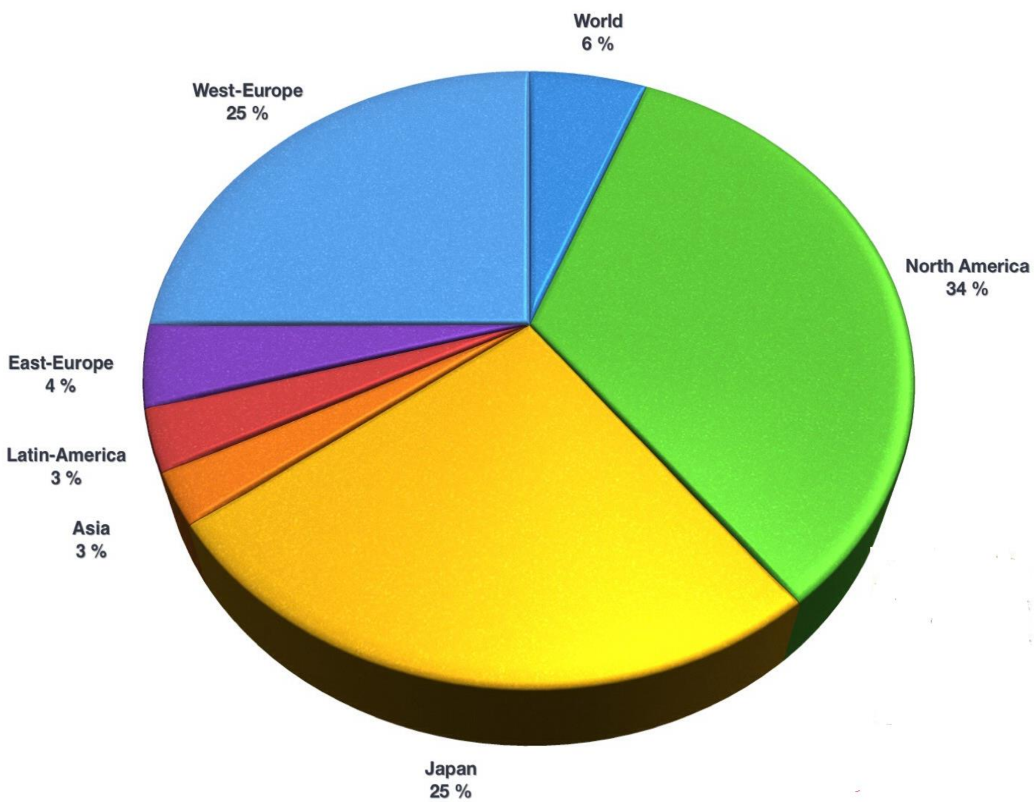
R&D opportunity	Applications	Estimated annual energy savings opportunity (TBtu/yr)	Estimated annual carbon dioxide (CO_2) emissions savings opportunity (million metric tonnes [MMT]/yr)
Advanced non-thermal water removal technologies	Drying and concentration	500	35
"Super boilers" (to produce steam with high efficiency, high reliability, and low footprint)	Steam production	350	20
Waste heat re			
Hybrid distill			
New catalysts (to improve y processes)			
Lower-energy, high-temperature material processing (e.g., microwave heating)	Crosscutting	150	10
Advanced high-temperature materials for high-temperature processing	Crosscutting	150	10
Net-shape and near-net-shape design and manufacturing	Casting, rolling, forging, additive manufacturing, and powder metallurgy	140	10
Integrated manufacturing control systems	Crosscutting	130	10
Total		**2,210**	**155**

- DOE estimates that 40% of the energy used in industrial drying can be saved with non-thermal technologies annually. This would save industry $16+B/year.

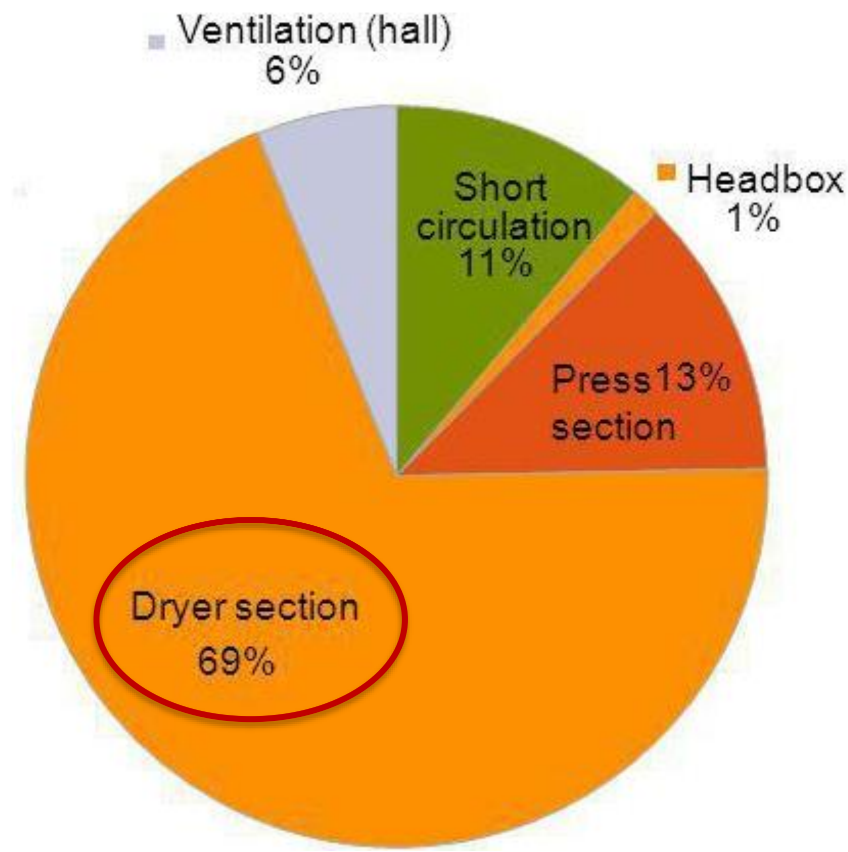
US Department of Energy, *Quadrennial Technology Review*, September 2015, Table 6.2, p. 189.

Drying – Paper Industry

World paper consumption



Energy consumption in papermaking machine



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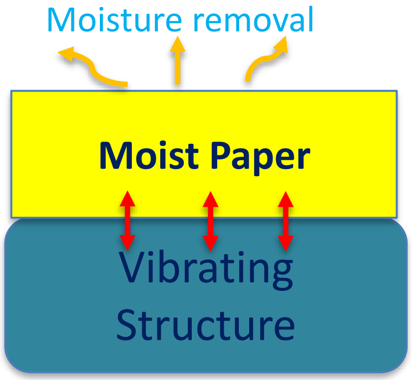
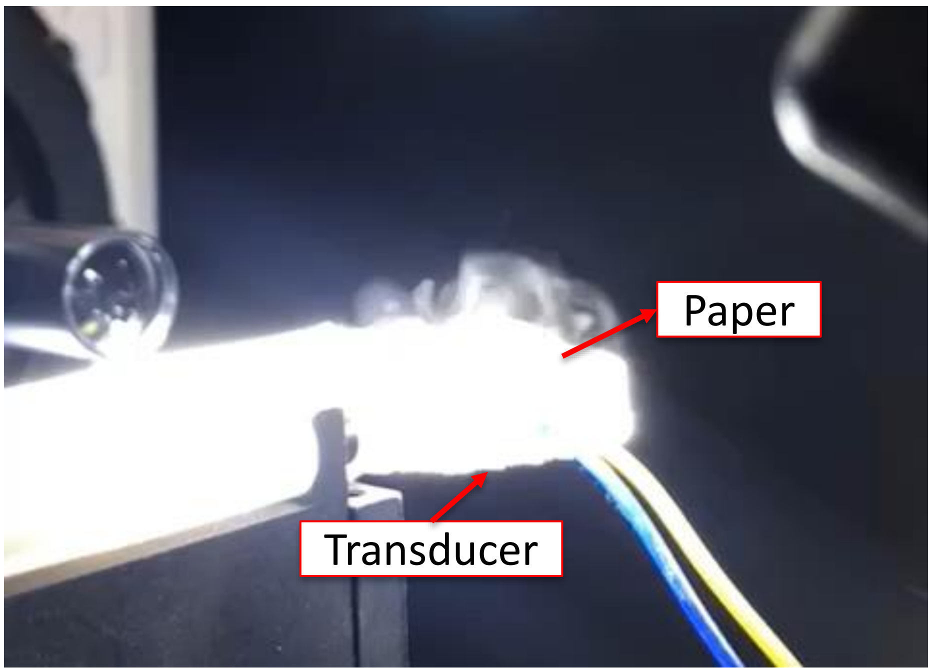
https://www.metso.com

Objectives

❖ Ultrasonic drying of paper



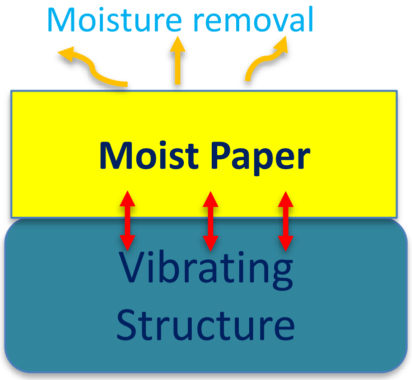


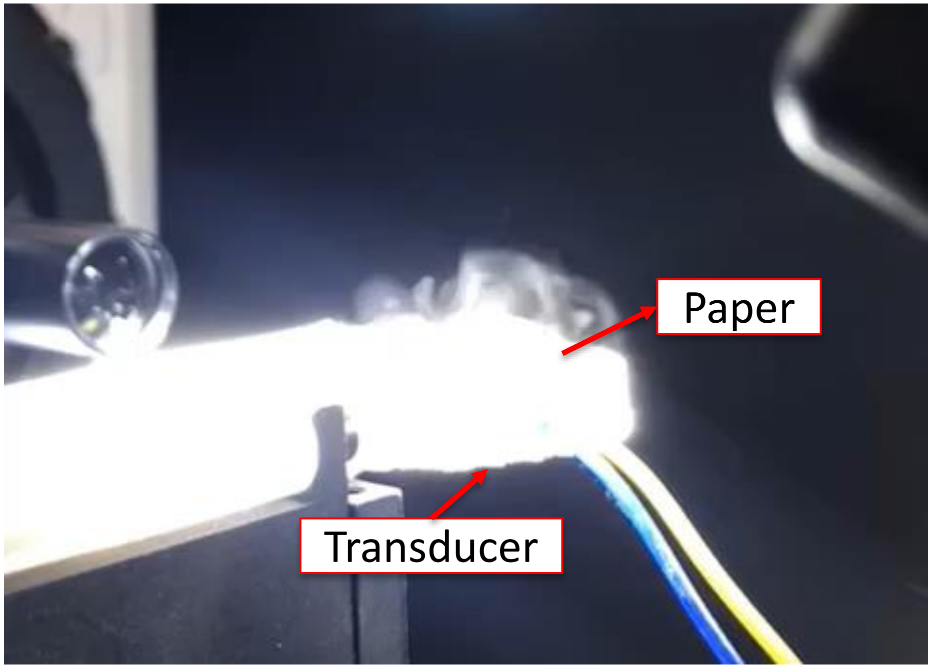
Ultrasonic drying of an over-saturated paper sample.

- ✓ Input power = 10 W
- ✓ Frequency = 1.7 MHz
- ✓ Transducer type = PZT mist generation transducer

Objectives

❖ Ultrasonic drying of paper

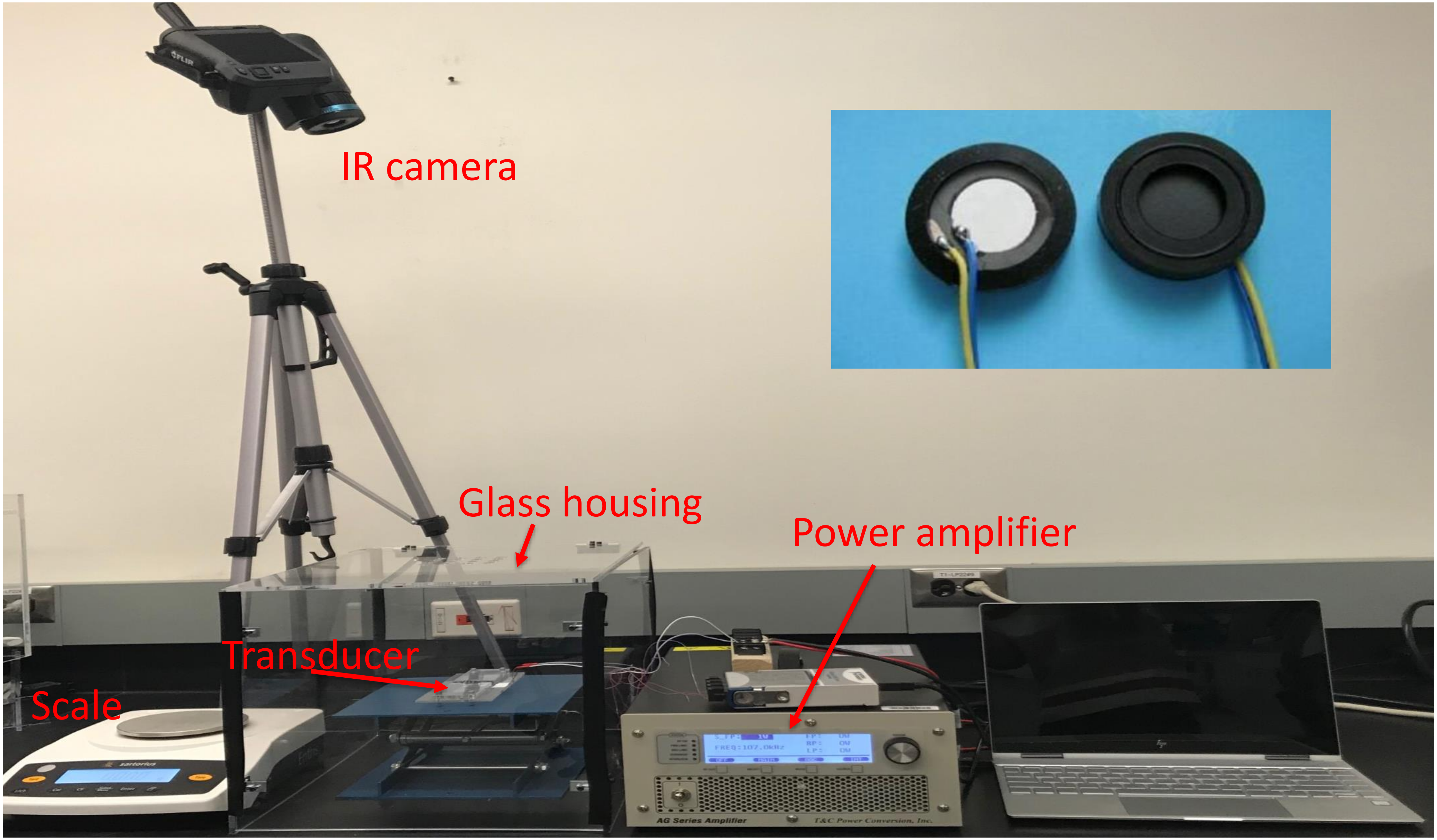




Ultrasonic drying of an over-saturated paper sample.

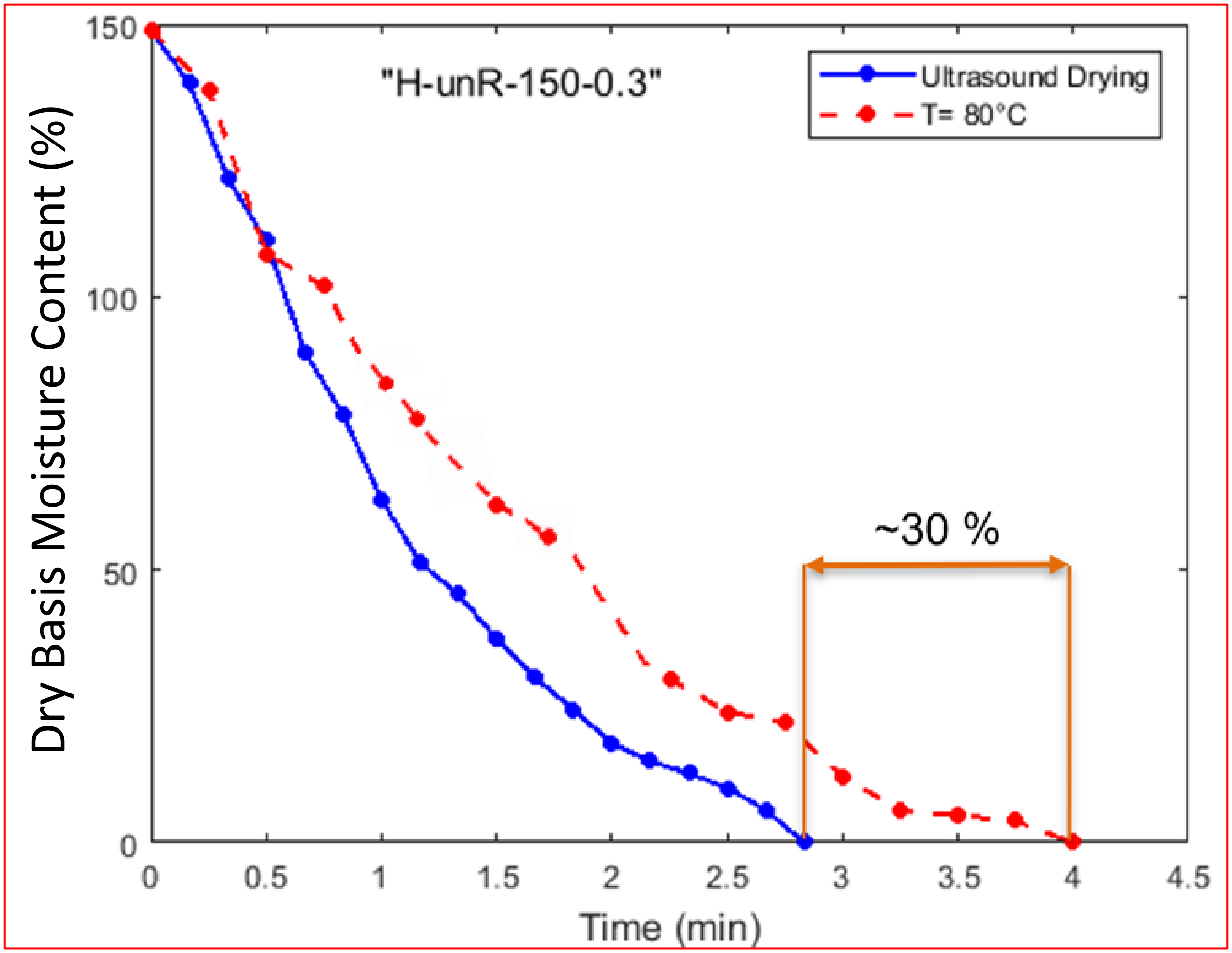
Advantages of ultrasonic drying:

- Lower drying time
- Higher energy efficiency
- Lower temperature for drying (non-thermal)
- Improvement of product quality
- It is a green technology



The major components in the experimental setup.

Comparing Ultrasonic Drying with Conductive Heat Drying



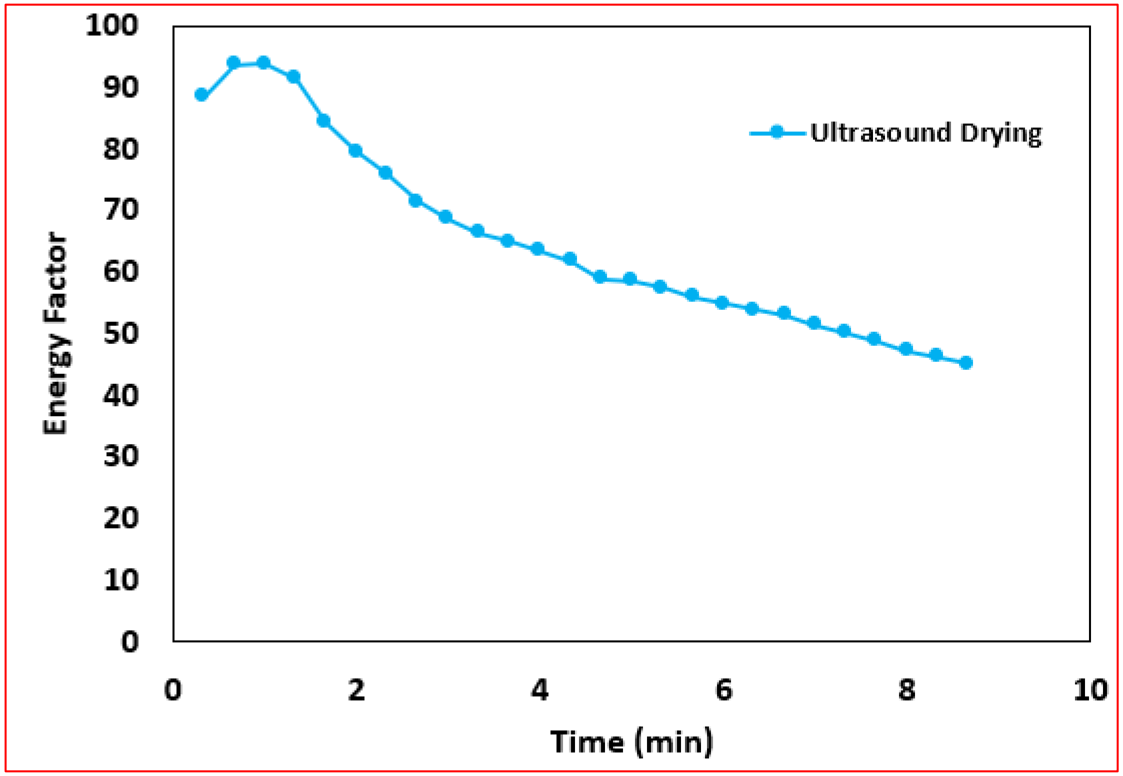
Comparing the drying curves for conductive heating with ultrasound drying.

Results

Energy Factor (EF)

$$\mathrm{EF} = \frac{(m_t - m_0) * h_{fg}}{\int LP(t)dt}$$

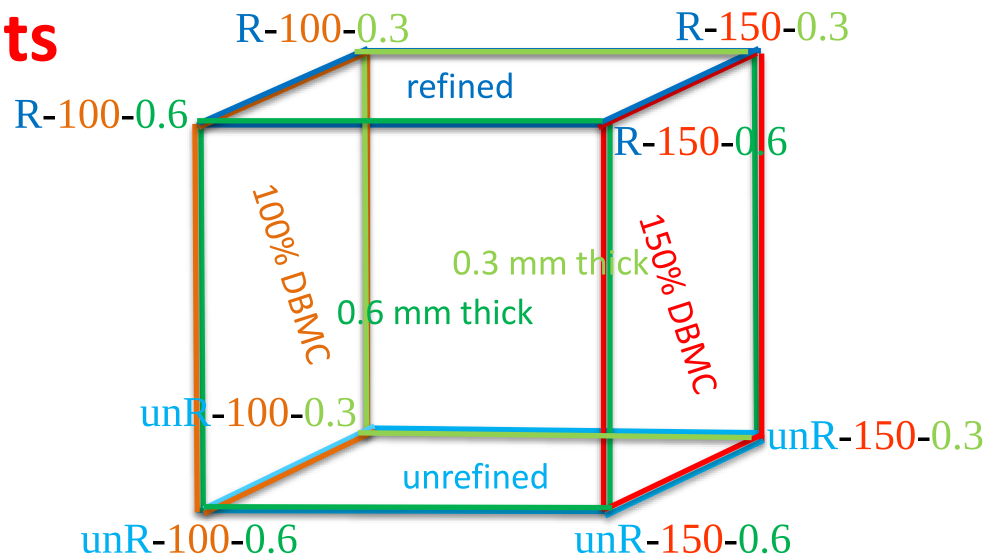
t: time
m: mass
h_{fg}: latent heat of water
LP: load power



Comparing the energy factors for different transducers and hand-sheet thickness = 0. 8 mm.

✓ Ultrasound drying can increase the energy efficiency by almost 40-90 times.

2^3 Factorial Design of Experiments



Refined: R
Unrefined: unR
Hardwood: H
Softwood: S

Abbreviation	Factors		
	Refining Condition	Initial Moisture Content - DBMC (%)	Thickness (mm)
H or S-unR-100-0.3	Unrefined	100	0.3
H or S-unR-150-0.3	Unrefined	150	0.3
H or S-unR-100-0.6	Unrefined	100	0.6
H or S-unR-150-0.6	Unrefined	150	0.6
H or S-R-100-0.3	Refined	100	0.3
H or S-R-150-0.3	Refined	150	0.3
H or S-R-100-0.6	Refined	100	0.6
H or S-R-150-0.6	Refined	150	0.6
H or S-Center Point	50%Unrefined & 50%Refined	125	0.45

2^3 Factorial Design

Total Drying Time (sec) = C_0 + C_1 * (Initial MC) + C_2 * (Basis Weight) + C_3 * (Refining Condition) + C_4 * (Initial MC) * (Basis Weight) + C_5 * (Initial MC) * (Refining Condition) + C_6 * (Basis Weight) * (Refining Condition) + C_7 * (Initial MC) * (Basis Weight) * (Refining Condition)

R-Sq = 99.47%

Term	Coef.
Constant	108.111
Initial MC	-0.222222
Basis Weight (g/m2)	0.330409
Refining Condition	24.6667
Initial MC*Basis Weight (g/m2)	0.00146199
Initial MC*Refining Condition	-0.333333
Basis Weight (g/m2)* Refining Condition	-0.085526
Initial MC*Basis Weight (g/m2)*Refining Condition	0.00219298

In the above equation, since the Refining Condition is qualitative:
Refined pulp → Refining Condition = 1
Unrefined pulp → Refining Condition = -1

Expected Impact

- ✓ Providing the Pulp & Paper industry with basic understanding of ultrasound mechanism for water removal under various operating conditions.
- ✓ Reducing the temperature and time for drying (energy savings).
- ✓ Improving the product quality.
- ✓ Contributing to the design of smart dryers.

Thank you for your attention :)

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