Large Scale Transport of Biomass Feedstock through Pipeline for Production of Fuels and Chemicals

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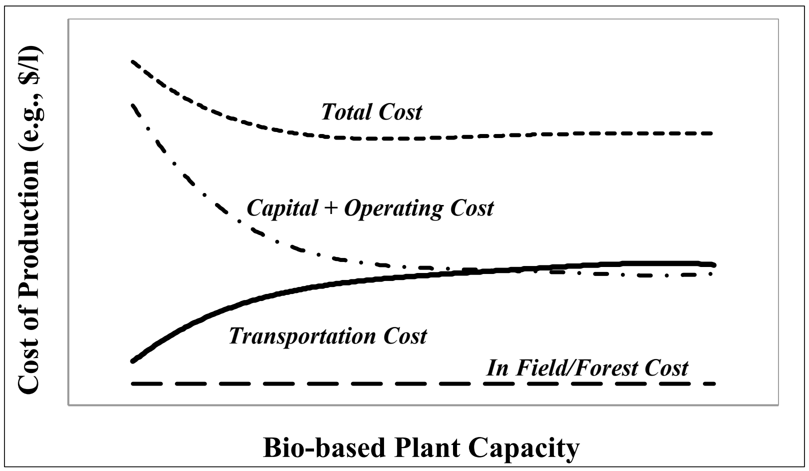
RESEARCH MOTIVATION

Optimum size of field/forest based biomass facility



Ruth, 1999
Jenkins, 1997

Corbis.com

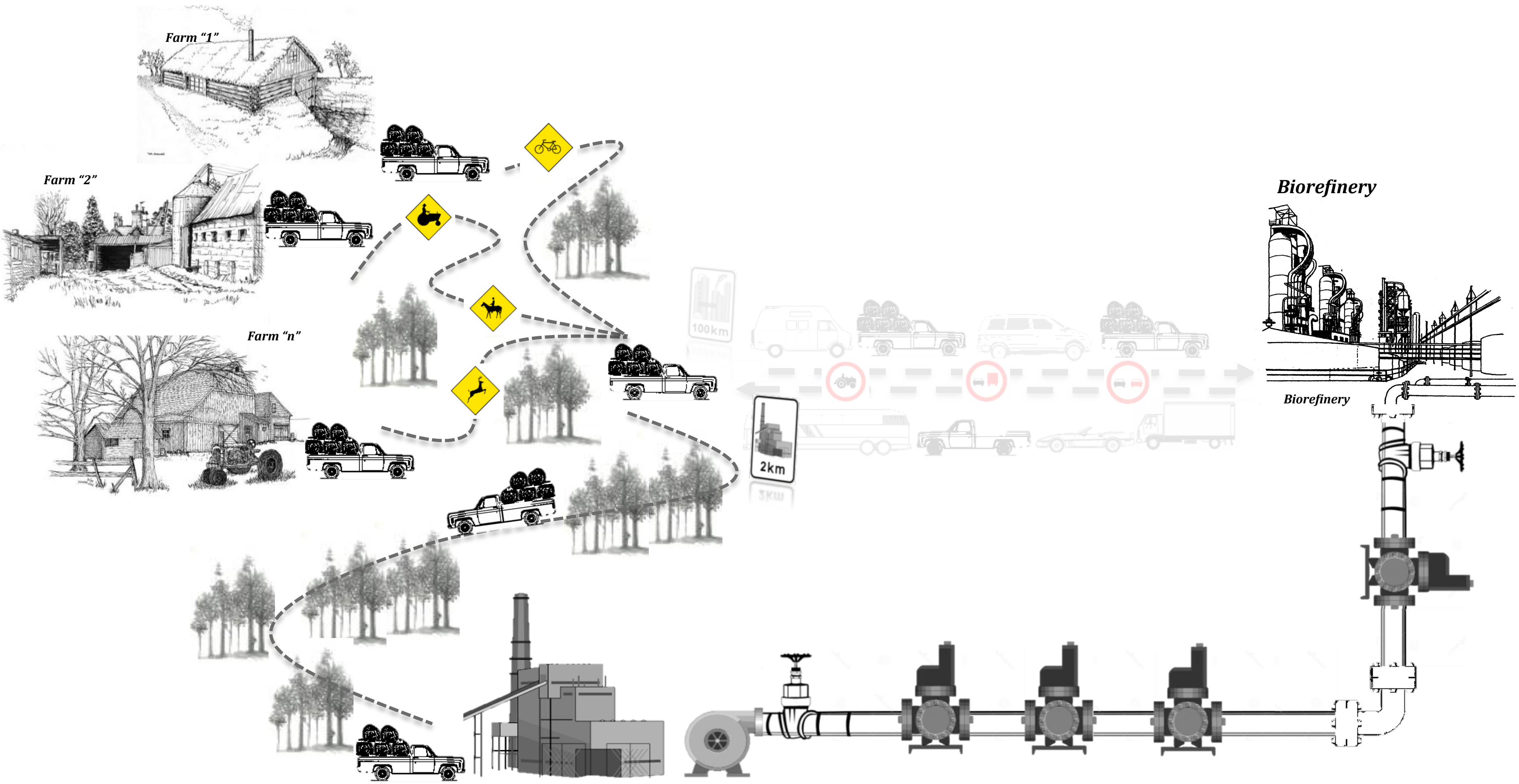
Issues in large-scale utilization of biomass

- ❑ *2 M dry t corn stover per year*
- ❑ *Logistics: 15 standard highway trucks per hour*
- ❑ *Producing 20,000 barrel (0.2 Ml) ethanol daily*
- ❑ *Typical oil refinery capacity over 850,000 barrel (10 Ml) daily*

Kumar et al., 2003 & 2004

- ❑ *4.3 M t of wood chips per year*
- ❑ *Logistics: one chip van (36 t capacity) every four minutes*
- ❑ *Producing 900 MW electricity (typical fossil fuel-based power plant capacity)*

THE IDEA OF BIOMASS PIPELINE HYDRO-TRANSPORT



Pre-processing Facility

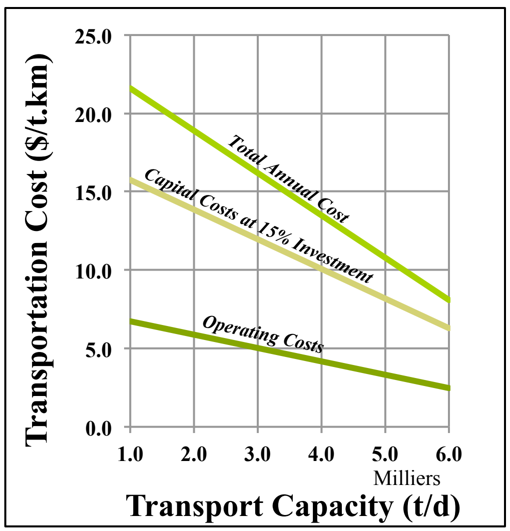
Pipeline + Booster Stations

HISTORY OF BIOMASS PIPELINE HYDRO-TRANSPORT

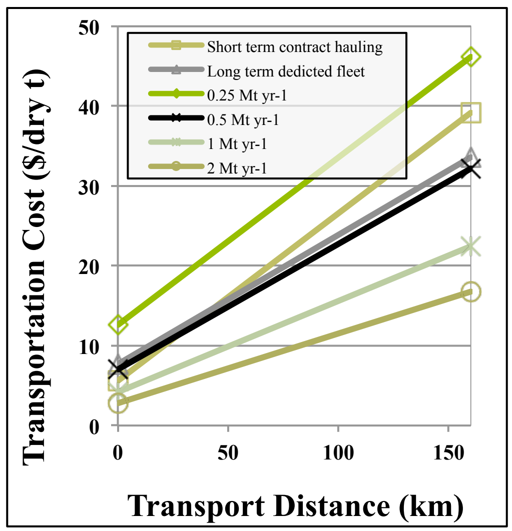
Technical feasibility of biomass pipeline hydro-transport

- *Nora Blatch, Cornell University, 1906*
- *Pipeline transport of wood chip-water mixture (laboratory-scale), PAPRICAN, 1960's*
- *Pipeline transport of wood pulp suspensions (short distance), Pulp and paper industry*
- *No study on pipeline hydro-transport of agricultural residue biomass*

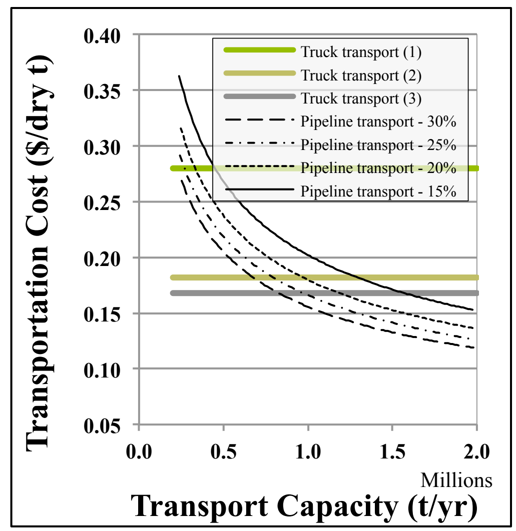
Economic feasibility of biomass pipeline hydro-transport



Wasp et al., 1967

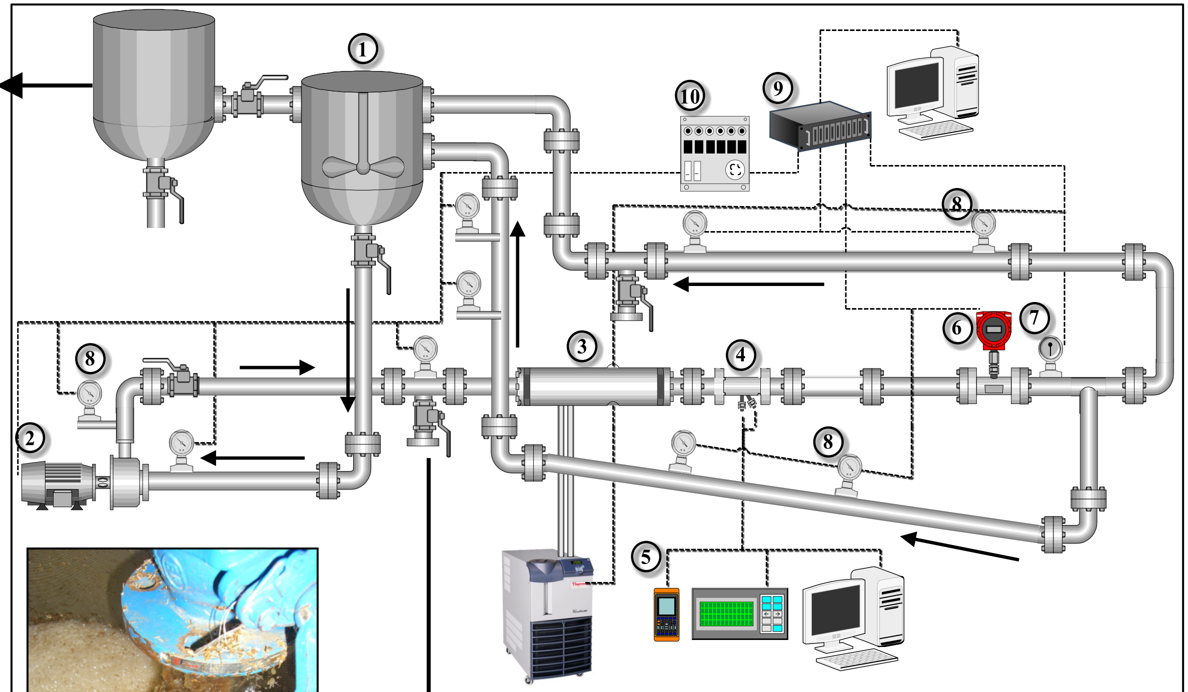


Kumar et al., 2004



Kumar et al., 2005

EXPERIMENTAL METHODOLOGY IN LARGE-SCALE FLUIDS LABORATORY AT UOFA



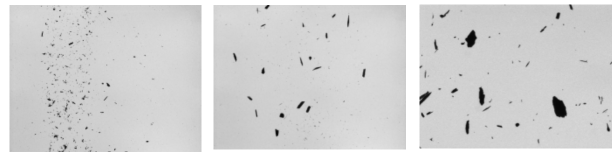
Pipeline facility in Large Scale Fluids laboratory - schematic diagram

PARTICLE SIZE ANALYSIS (CamSizer® P4)

Woodchips particles

d_{50}=1.91 mm	***d_{50}=1.35 mm***	***d_{50}=3.82 mm***	***d_{50}= 7.18 mm***

CamSizer Realtime Photos

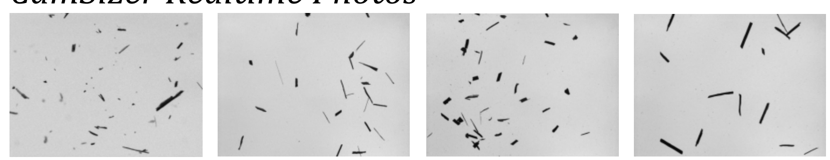


600 µm ***<1.35 mm*** ***<3.82 mm***

Wheat straw particles

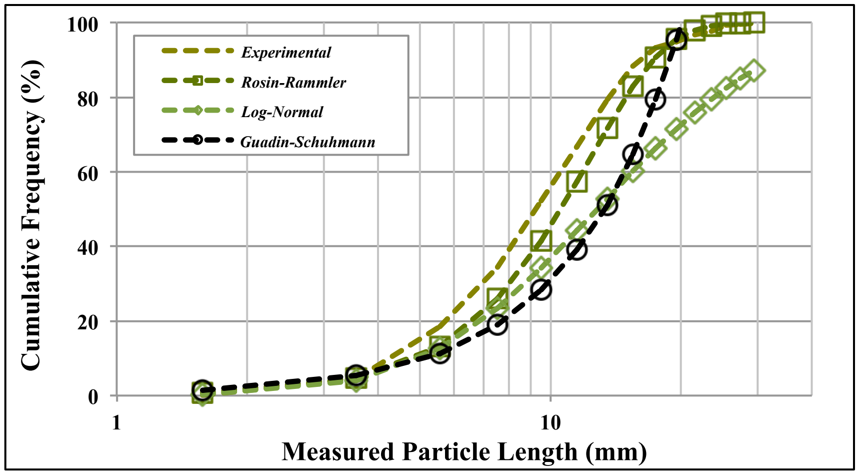
19.2 mm (d_{50}=9.7 mm)	***6.4 mm (d_{50}=6.5 mm)***	***3.2 mm (d_{50}=4.8 mm)***	***<3.2 mm (d_{50}= 1.9 mm)***

CamSizer Realtime Photos

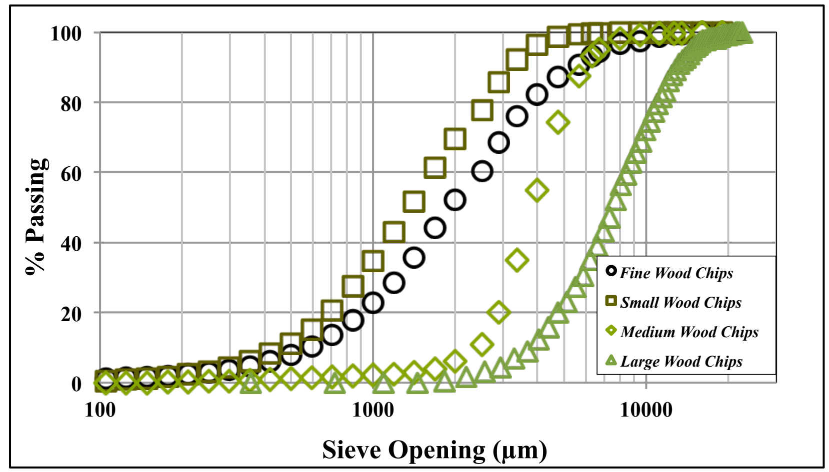


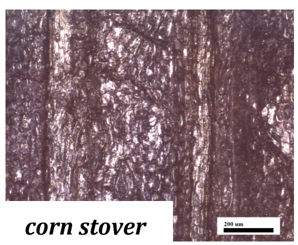
PARTICLE SIZE ANALYSIS (Digital Image Processing)

*Triple distribution functions and image analysis of 19.2 mm (3/4") **corn stover***



*Accumulative particle size distribution of **woodchips** particles*



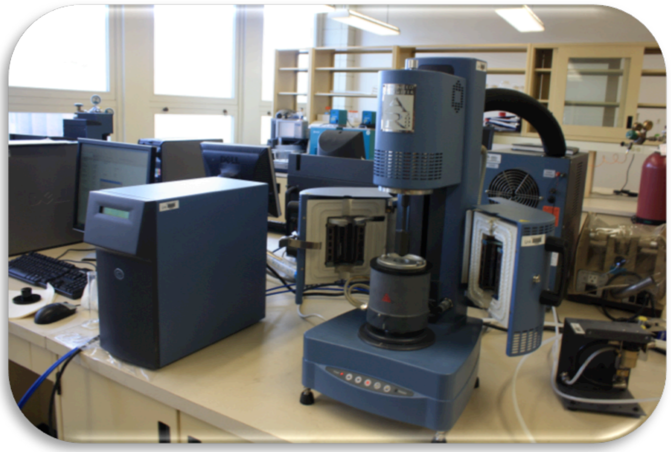


Confocal scanning microscope images of wheat straw and corn stover particles at 10x magnification

Material	Average Roughness (µm)	Highest Peak (µm)	Lowest Valley (µm)	Kurtois
Wheat Straw	7.9	130.2	149.9	9.3
Corn Stover	53.1	207.3	250.8	3.3

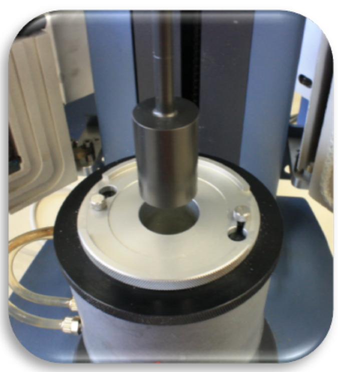
J. Biosystems Engineering Vaezi et. al., 2013

SLURRY RHEOLOGICAL MEASUREMENTS

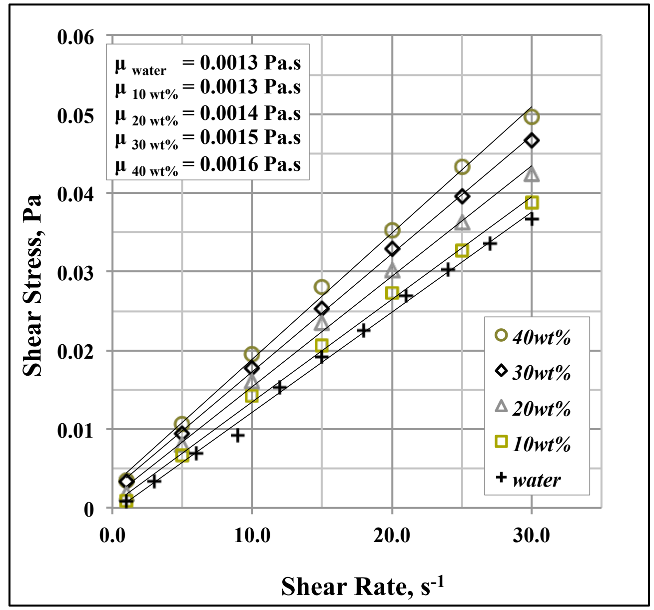


Rotational viscometer (AR 2000; TA Instrument, New Castle, DE, US) with concentric cylinder geometry

Slurry Filtration Process



Concentric Cylinder Geometry



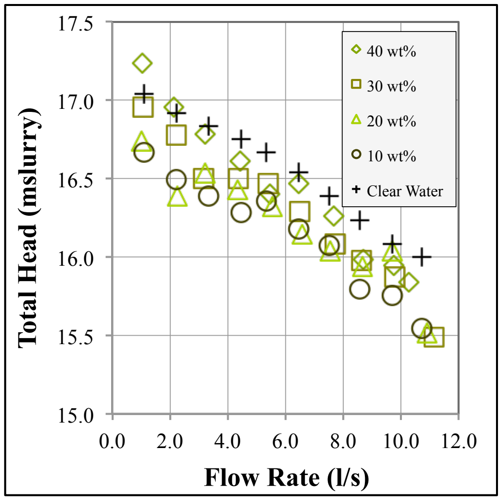
Viscosity of the filtered carrier fluid of 10 to 40 wt% suspensions of <1/8” wheat straw particles at 15°C

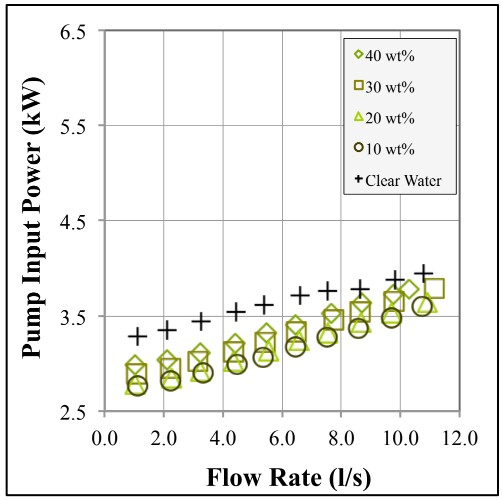
Vaezi et al, Investigation into the mechanisms of pipeline transport of slurries of wheat straw and corn stover to supply a bio-refinery, J. Biosystems Engineering, 2014

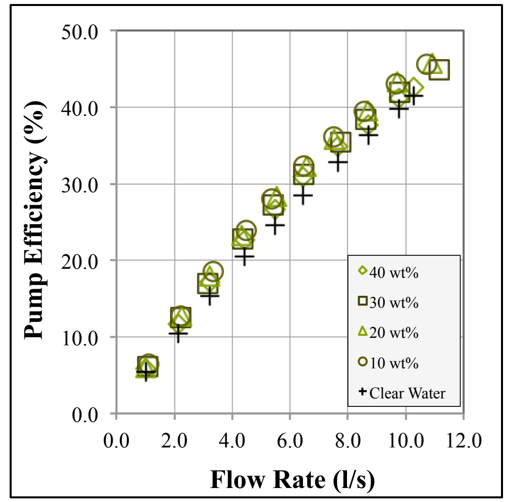
PUMP PERFORMANCE EVALUATION

Centrifugal slurry pump performance evaluation

Performance characteristics of <1/8" wheat straw particles slurries at 1765 rpm

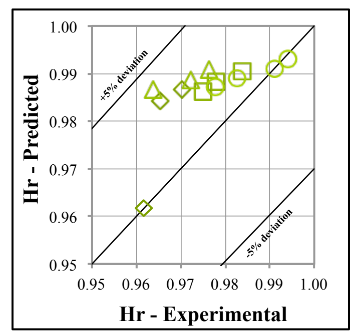






Empirical correlation development

to predict the head ratio while pumping agricultural residue biomass slurry with less than 5% deviation

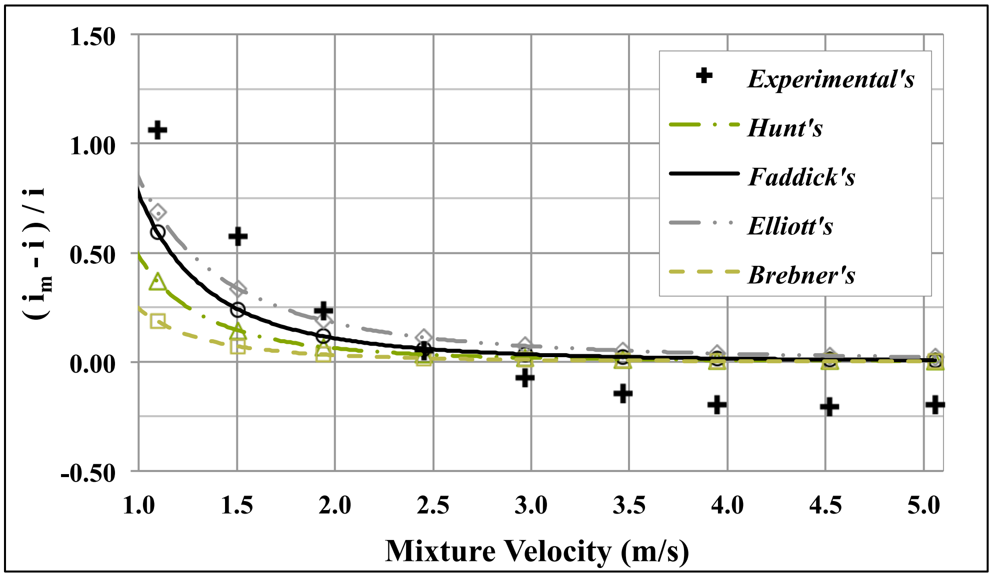


$$H_r = 1 - [(0.4 C_w - 0.3)(0.1 d_{50}^2 + 28)$$

WOOD CHIPS CORRELATIONS APPLICABILITY

Friction loss behavior comparison

Empirical correlations by Hunt (1976), Faddick (1963), Elliot (1963), and Brebner (1964)



Friction loss parameter vs. mixture velocity for 6.5% slurry of 6.4 mm corn stover particles

$$\text{Hunt's}: \left(\frac{i_m - i}{i}\right) = 197\left(\frac{D_{pipe}^{0.97}\, g^{1.312}\, \upsilon^{0.342}}{V_m^{2.964}}\right)\left(\frac{C_v}{1-C_v}\right)^{0.838+0.93\ln(1-k)}$$

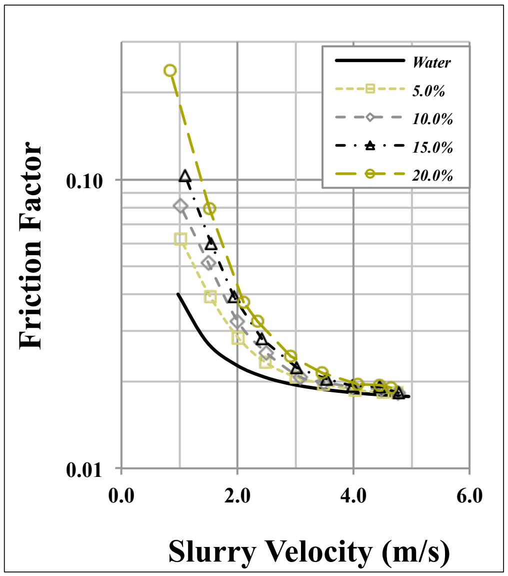
$$\text{Elliot's}: \left(\frac{i_m - i}{i}\right) = 211\, C_v\left(\frac{D_{pipe}^{0.5}}{V_m}\right)^{2.25}$$

$$\text{Faddick's}: \left(\frac{i_m - i}{i}\right) = 2.51\, C_v\left(\frac{4\, g\, D_{pipe}}{V_m^2}\right)^{1.42}$$

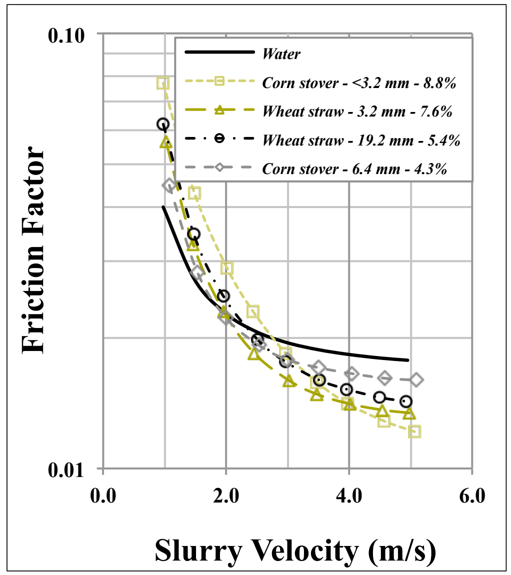
$$\text{Brebner's}: \left(\frac{i_m - i}{i}\right) \cong 18\, C_v\left(\frac{V_m^2}{g\, D_{pipe}}\right)^{-1.5}$$

FRICTION LOSS BEHAVIOUR STUDY

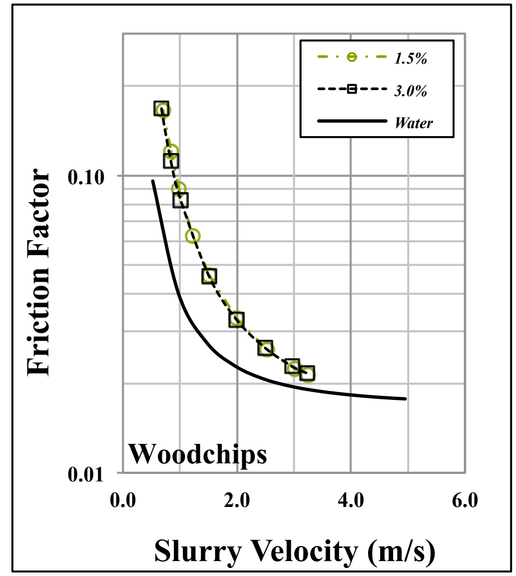
Sand, wheat straw and woodchips longitudinal friction loss measurements



***play sand** particles*



***wheat straw** particles*
wood fibers



Woodchips

Slurry friction loss correlation development

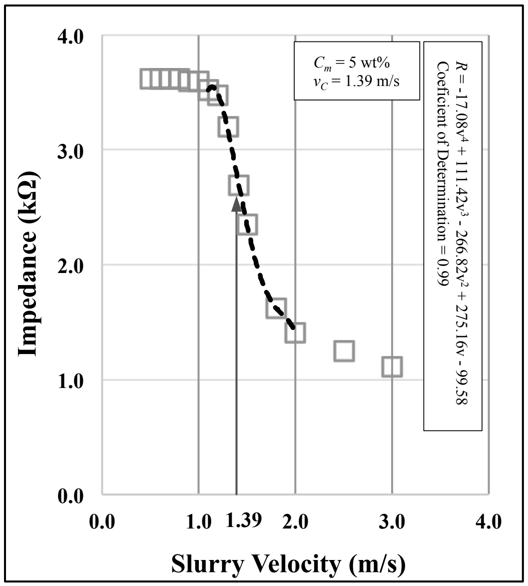
$$\Delta H/L=[\sum_{n=1}^{3}(\alpha_n S^n+\beta_n V^n+\gamma_n C_d^n+\delta_n V^n$$

Coefficients for numerical correlation

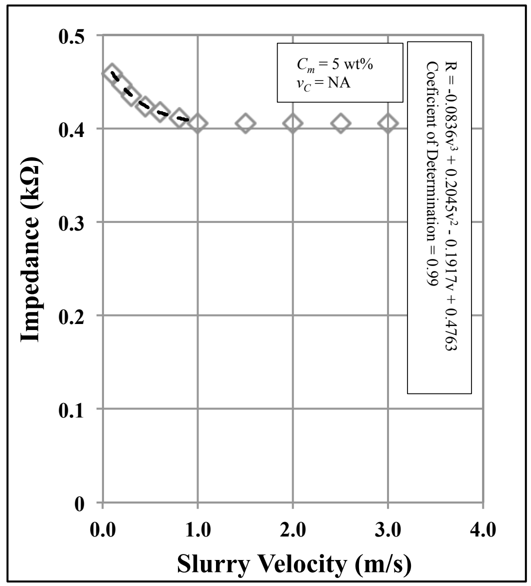
Coefficient	Dummy		
	n = 1	*n = 2*	*n = 3*
α	1.22465	-1.97098	0.64855
β	0.00000	0.16389	0.00000
γ	0.00000	0.00000	0.00066
δ	0.00000	-0.00104	0.00000
D_0		0.0508 m	

CRITICAL SETTLING VELOCITY CALCULATION

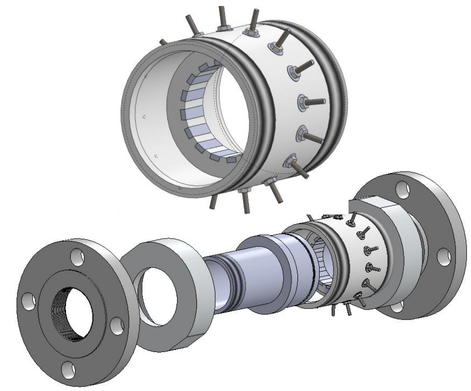
High-Frequency Impedancemetry to Calculate Critical Settling Velocity

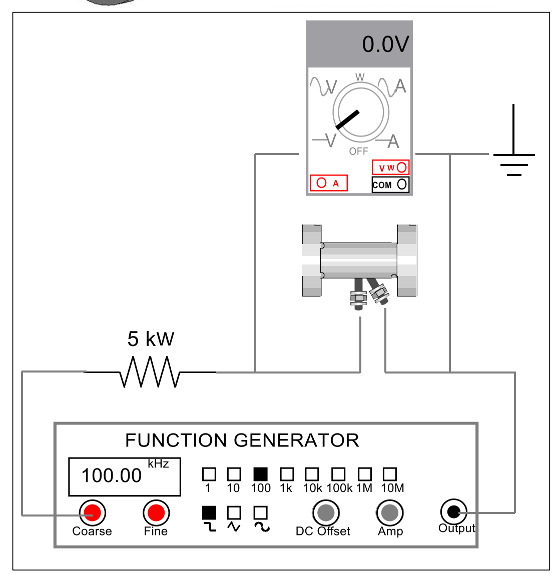


Play Sand



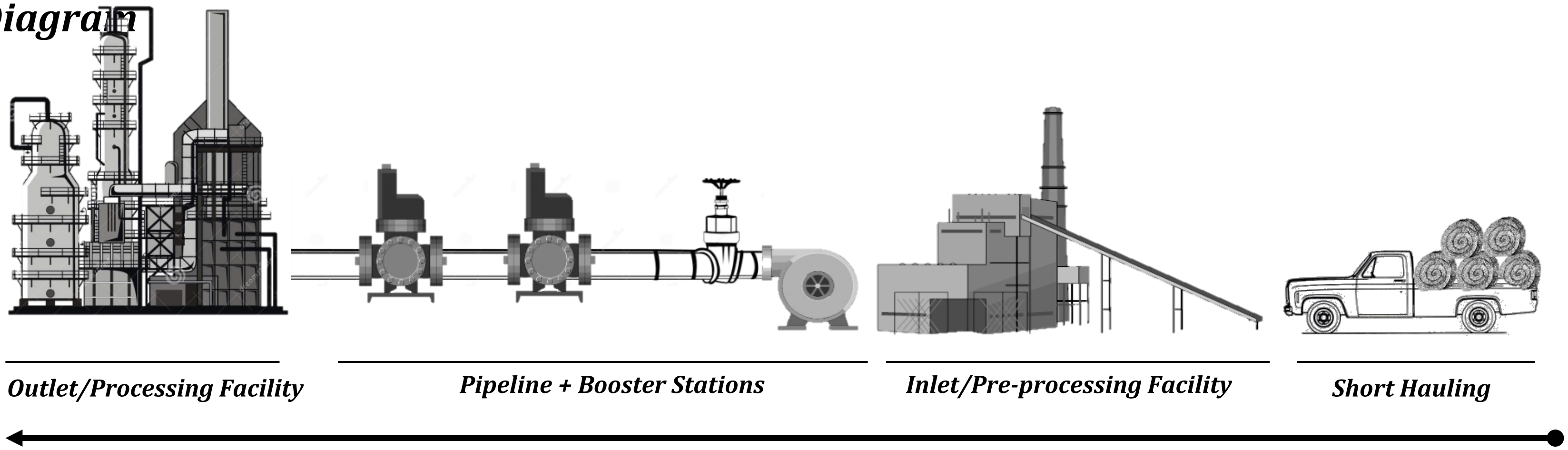
Wheat Straw





ECONOMIC FEASIBILITY

Agricultural and Forest Residue Biomass Pipeline Hydro-transport Process Flow Diagram



Research Objective

- ***Study the economic feasibility of pipeline hydro-transport of agricultural and forest residue biomass***
  - *Cost of transportation*
  - *Capacity and distance*

Techno-economic Modeling

General Technical Parameters

Item		Description/Value
Pipeline capacity		250,000 to 4,000,000 M dry t/yr
Average transportation distance		50 to 300 km
Biomass particle type		wheat straw and woodchips
Biomass particle size	Agricultural	Nominal: <3.2, 3.2, 6.4, 19.2 mm (d_{50}: 1.9 to 8.29 mm)
	Forest	d_{50}: 1.9 to 7.18 mm
Particle saturated moisture content	Agricultural	82%
	Forest	70%
Saturated biomass particle density	Agricultural	1050 kg/m^3
	Forest	1115 kg/m^3
Dry matter solid mass content	Agricultural	2 to 8.8%
	Forest	2 to 7.2%
Slurry velocity		1.5 to 4.5 m/s
Velocity of water in water return pipeline		2 m/s
Slurry pressure drop correlation		$\Delta H/L = \left[\sum_{n=1}^{3} \left(\alpha_n S^n + \beta_n V^n + \gamma_n C_d^n + \delta_n V^n C_d^n\right)\right](D/D_0)^{-1.2}$ $\left(\frac{i_m - i}{i}\right) = 2.51\, C_v \left(\frac{4\, g\, D_{pipe}}{V_m^2}\right)^{1.42}$
Slurry and water pump efficiency		80%
Maximum pressure of the pump		3100 kPa

TECHNO-ECONOMIC MODELING (CONT'D)

General Economic Parameters

Item		Values
Inflation rate		2.1%
Discount rate		10%
Life of pipeline		30 yr
Life of pump		20 yr
Capacity factor of pipeline		0.85
Maintenance cost of		
	- equipment	3% of capital cost
	- pipeline	0.5% of capital cost
Power cost		50 $/MWh
Engineering cost		10% of total capital cost
Contingency cost		5% of total cost
Scale factor		0.75

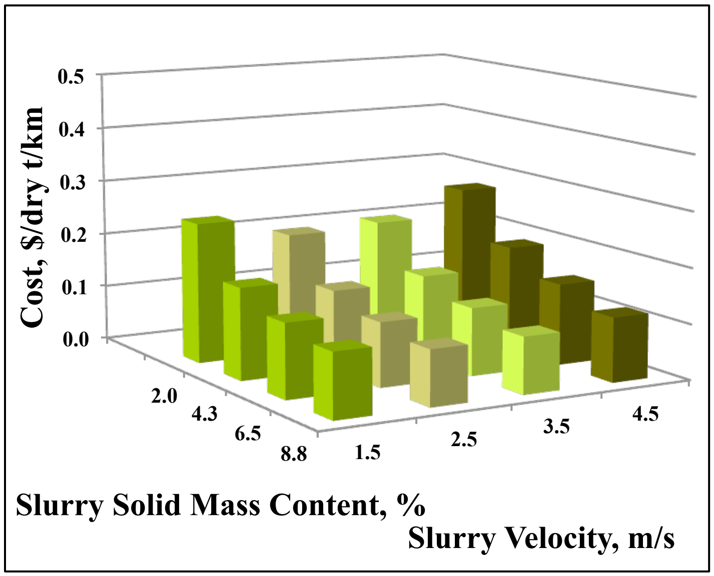
Cost of biomass transportation by truck in North America (2014 USD)

Biomass	**DFC** ($/dry t)	**DVC** ($/dry t/km)	**Total Cost** (150 km **-** $/dry t)
Wheat straw	6.66	0.27	47.16
Corn stover (NREL)	9.45	0.24	45.45
Switchgrass	10.77	0.15	33.27
Hay and forage	9.20	0.16	33.2
Hay (less than 100 km)	9.02	0.40	69.02

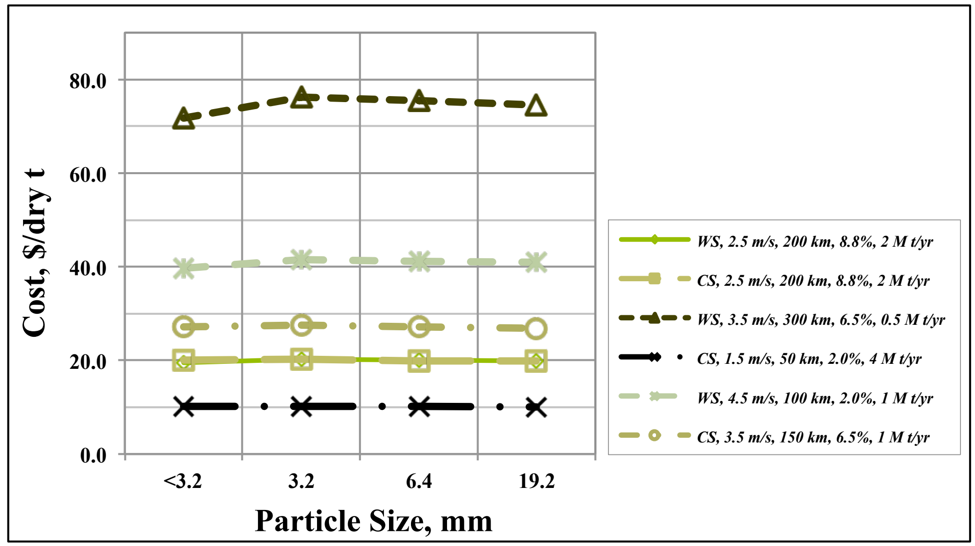
SENSITIVITY ANALYSIS

Effective Variables:

(1) biomass particle type, (2) biomass particle size, (3) pipeline capacity, (4) pipeline length, (5) slurry solid mass content, (6) slurry velocity

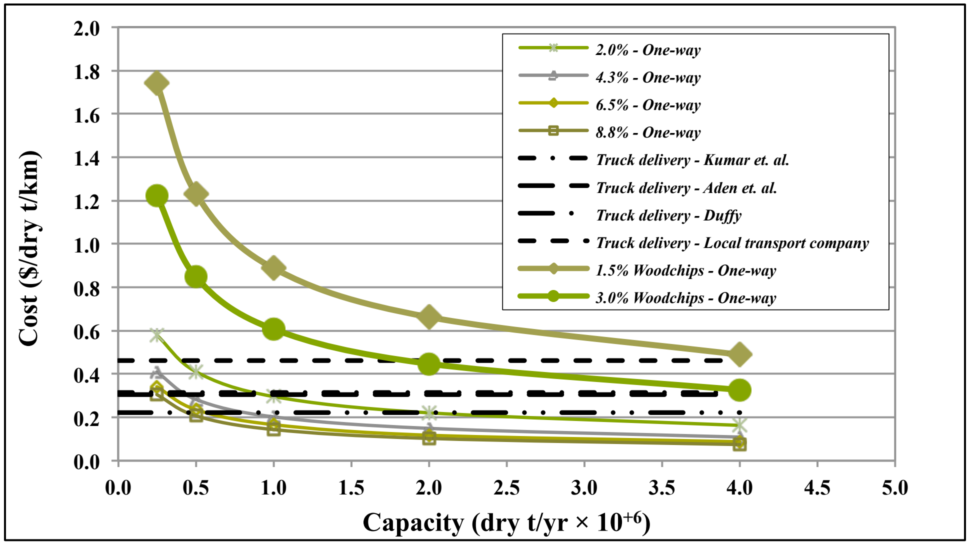


***Distance variable cost** of **one-way** pipeline hydro-transport of **2,000,000 dry t/yr** of **<3.2 mm wheat straw particles** over a **200 km distance** as a function of slurry velocity and solid mass content*

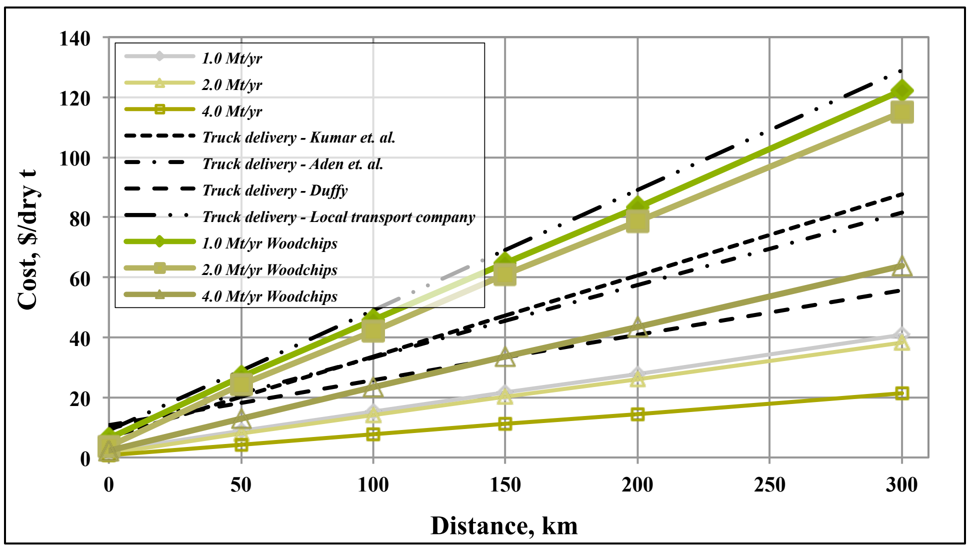


Cost of pipeline transport of various biomass particle sizes

RESULTS (one-way pipeline)



*Costs of pipeline hydro-transport of **<3.2 mm wheat straw particles ,** as well as **woodchips** at **2.5 m/s** over **150 km** as a function of pipeline capacity and slurry solid mass content*



*Cost of pipeline transport of **8.8% solid mass content** slurry of **<3.2 mm wheat straw particles** and **3.0% solid mass content of woodchips** at **2.5 m/s** as a function of pipeline length and capacity*

CONCLUSIONS

- *Agricultural residue biomass can be successfully pipelined over a wide range of particle sizes and slurry concentrations*
- *Wood fibres behave similar to wheat straw fibres when pumped into pipeline*
- *Pipeline transport of wood chips is limited by the particle size and slurry concentration*
- *Wood chips behave similar to conventional solids when pumped into pipeline*
- *Numerical correlations previously developed for fibrous agricultural residue biomass could be well used to predict the friction loss behavior of wood fibres*
- *The performance of the pump handling fibrous forest and agricultural residue biomass is positively affected vs. the pump handling water only*
- *Savings in pumping power could be obtained by replacing large chips by fine fibrous chips*

CONCLUSIONS

- *Numerical correlations developed for fibrous agricultural residue biomass could be well used to predict the friction loss behavior of wood fibres*
- *There is no concern with regard to the critical settling velocity of fibrous biomass particles in pipelines*
- *Economically considering, pipeline hydro-transport of agricultural residue biomass is favorable compare to truck mode of delivery*
- *Understanding the mechanical behavior of agricultural residue and wood chips biomass helps to optimize the design and the operating conditions of biomass pipelines and enable bio-based energy facilities to achieve higher capacities*

APPLICATIONS

- *Large-scale transport of biomass feedstock (agricultural and forest residue) for*
  - *Bio-fuel production via*
    - *Fermentation (bio-ethanol production)*
    - *Hydrothermal liquifaction*
    - *Hydrothermal gasification*
    - *Plantrose process (uses supercritical water to reduce costs in conversion of biomass to cellulosic sugars)*
  - *Pulp and paper production*

ACKNOWLEDGEMENT

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THANKS

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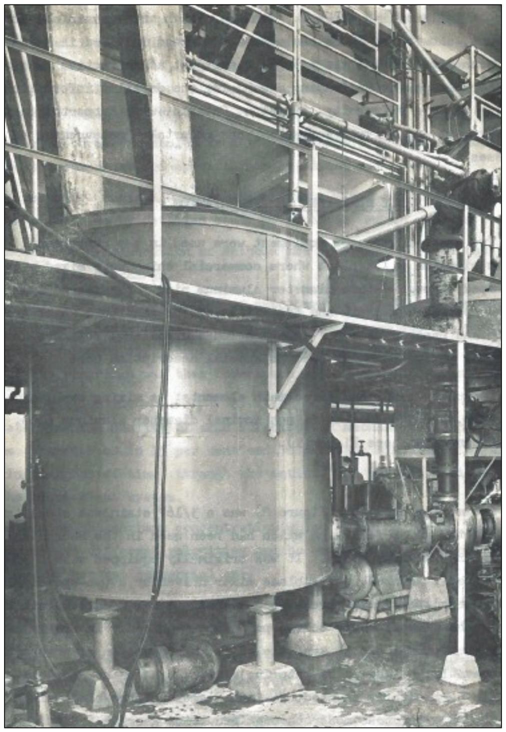
HISTORY OF FOREST RESIDUE BIOMASS PIPELINE HYDRO-TRANSPORT



Part of the PAPRICAN pilot plant

Photo credit: Pulp and Paper Research Institute of Canada, 1960

- In ***1958***, ***Elliott and de Montmorency*** at ***Pulp and Paper Research Institute of Canada*** installed a pilot plant comprised of 160 m of 200 mm diameter aluminum pipe to study the hydraulic transport of Spruce and Balsam fir wood chips in pipelines [1].
- In ***1962***, the R&D section of the ***Shell Pipeline Company*** studied hydro-transport of wood chip-water mixtures on a closed-circuit commercial pipeline facility of 1220 m length and 200 mm diameter at Houston, Texas [2].
- In ***1963***, ***Faddick*** presented measured the friction loss in wood chip pipelines based on studies with a 100 mm diameter aluminum pipe at ***Queen's University in Kingston, Ontario*** [3].

[1] Elliott DR, de Montmorency, WH; Pulp and Paper Institute of Canada; 1963.
[2] O'donnell JP; Oil and Gas Journal; 1964.
[3] Faddick RR; Kingston, Ontario: Queen's University; 1963.