The refining process and its effects on fibres interpreted through the lubrication theory

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Session 1 – Multiphase modelling of fiber suspensions

Outline

1- Some milestones to validate the lubrication theory in a global sense

2- How to relate it to *papermaking problems* and *concepts*: understanding the refining process and its effects on fibres?

3- What remains to be done?

Some milestones

- Rance and Steenberg (1951)

The tribology analyzes the lubrication and the wearing of two surfaces in relative motion.

It should help to better understanding the refining process and consequentely better controlling the effects on fibres.

What are these analogies? The common physical quantities are the followings:

- gap clearance, rotation frequency (or relative velocity), the mechanical pressure $\mathbf{P_m}$;

- the plate rugosity (*to define*);

- the apparent viscosity μ_{app} (*including the consistency*);

- the friction force, the normal bearing load, the friction coefficient.

Rance and Steenberg – results

Experimentations performed on a Valley beater and on a disc refiner during the refining process:

- the friction coefficient is decreasing;
- the friction coefficient increases with an increase of the normal force;
- an increase of the consistency leads to an increase of the friction coefficient and of the gap clearance.

These observations are analogous to the Stribeck's curve obtained in the lubrication theory:

The pulp suspension behaves as a lubricant, however the lubricant is altered during the refining process

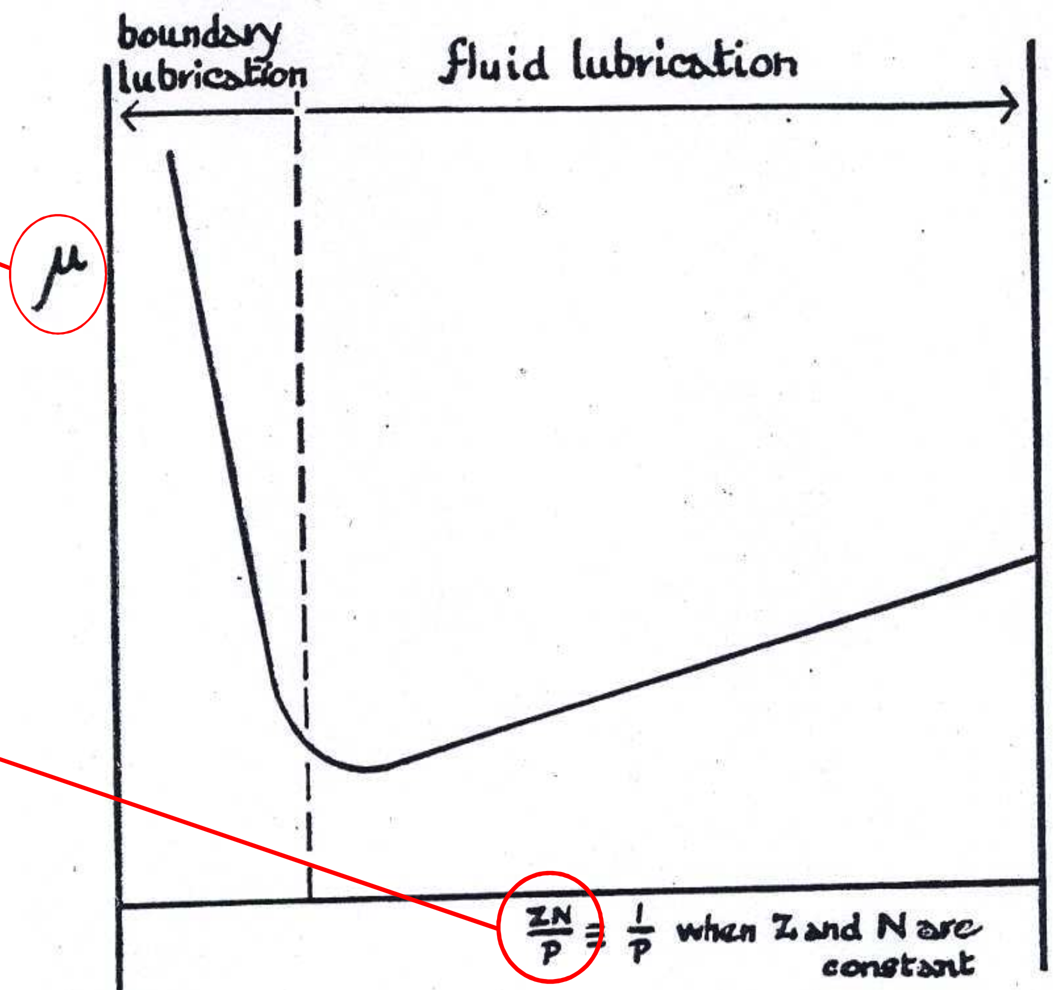
When the flow remains laminar between the two surfaces in the full fluid lubrication regime, the friction coefficient **f** only depends on : $\mu_{app}.N / P_m$

Stribeck's curve in lubrication theory

μ = coefficient de friction dans un système métal / huile

≈

f = friction coefficient of the pulp



- Z = viscosité du lubrifiant

≈ **Pulp apparent viscosity**

- N = vitesse de rotation axe

≈ **Rotation frequency**

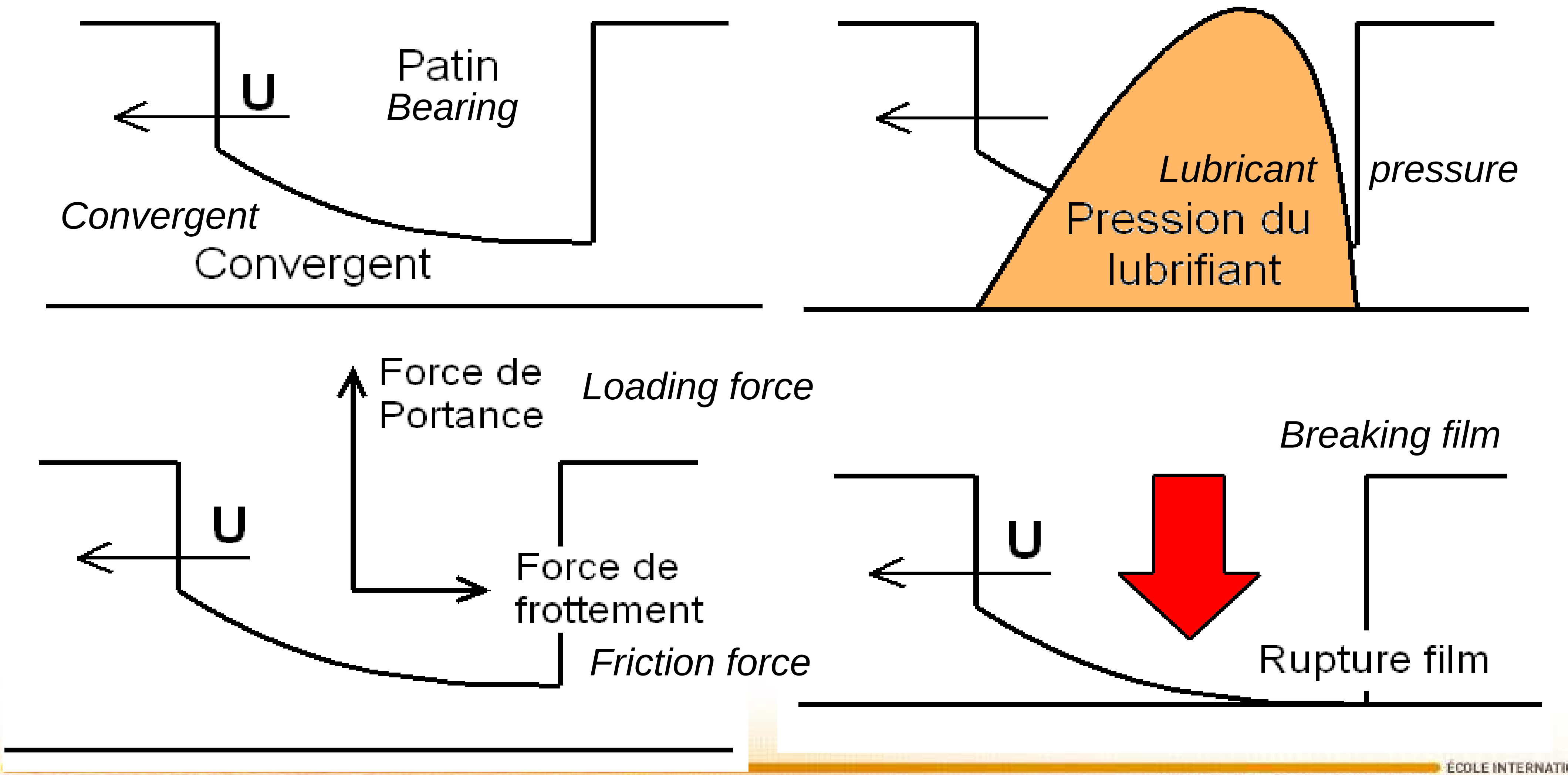
- P = pression mécanique

≈ **Pressure P_m**

H.F.Rance *The world's trade paper review*. 136 (3) 1951

Hydrodynamic approach

Hydrodynamic theory in a lubricated bearing load in a global sense



Definitions of engineering geometrical parameters of plates for disc refiners

<u>Angular parameters: 3</u>

α grinding angle of the rotor

β grinding angle of the stator

θ same sectorisation angle (rotor/stator)

<u>Grinding code (partial): 2</u>

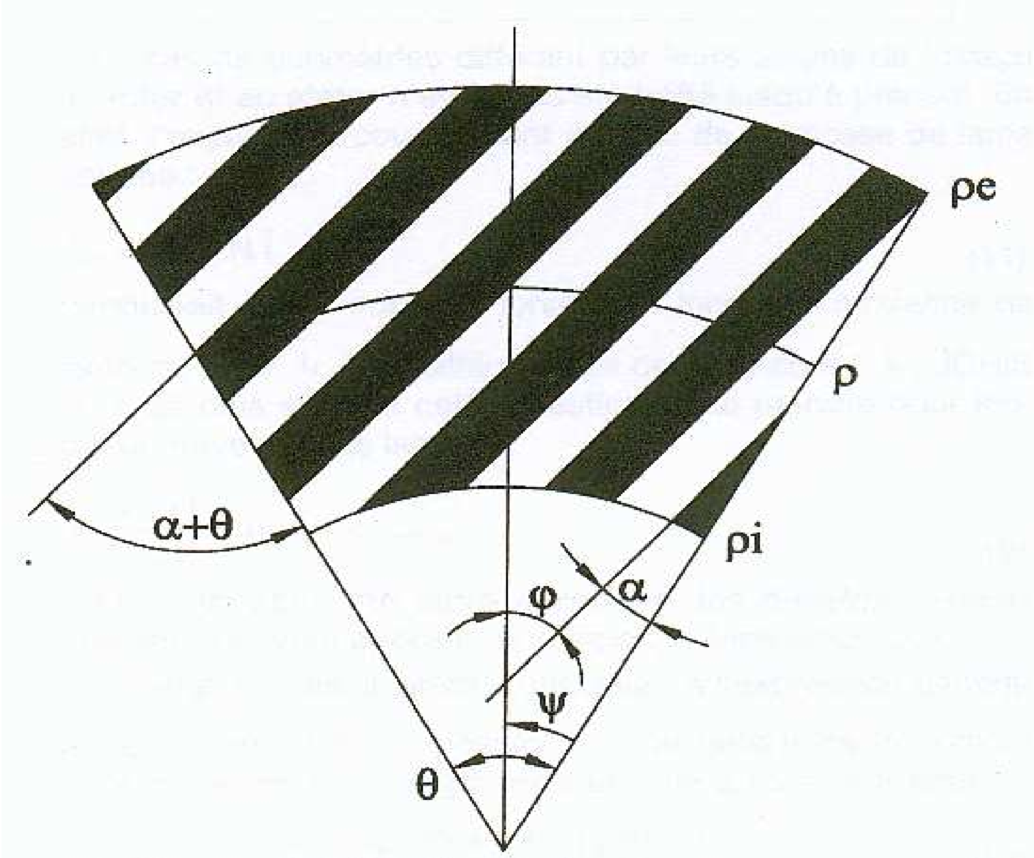
a width of bars (m)

b width of grooves (m)

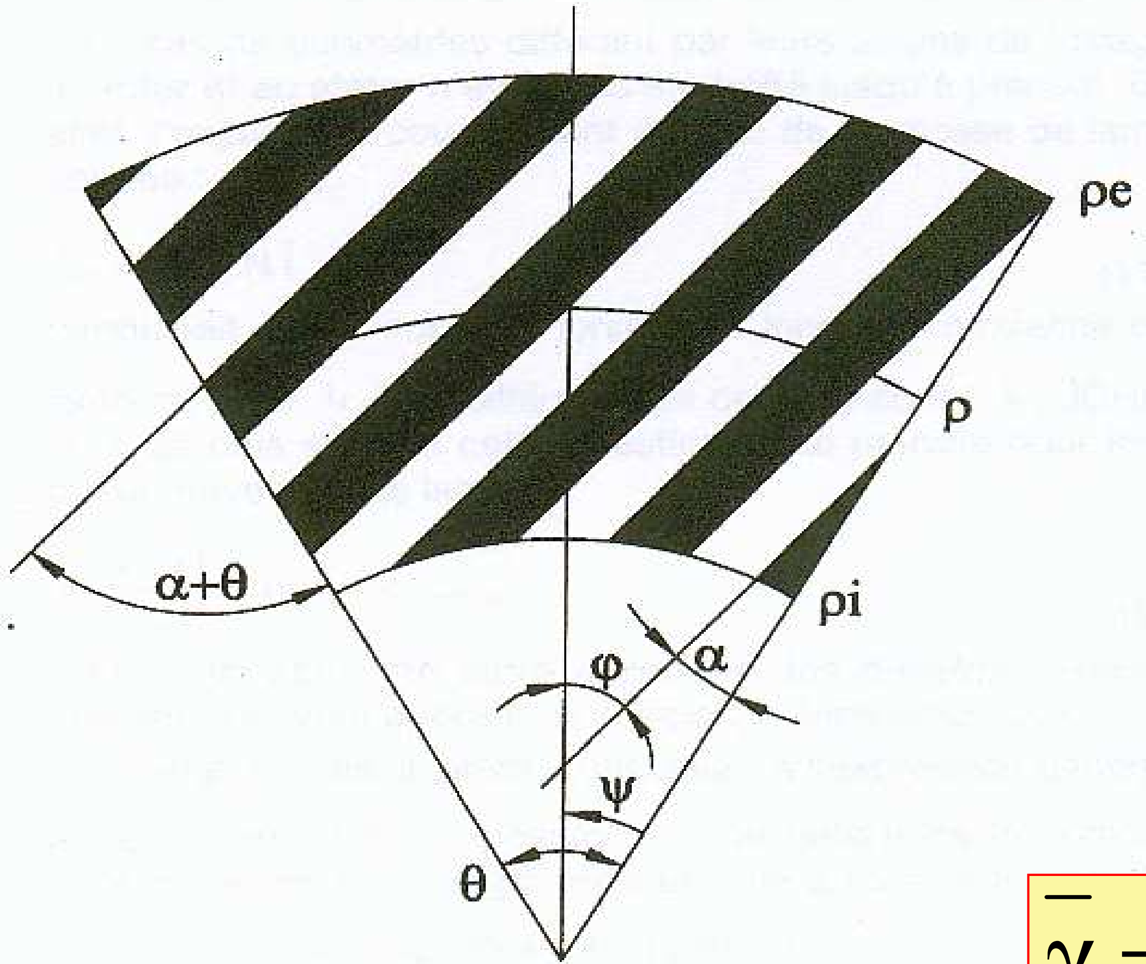
<u>Refiner:</u> 2

ρ_i internal radius of the corona (m)

ρ_e external radius of the corona (m)



Definitions of time average angular parameters



Angular parameters

$$\begin{cases} \overline{\Phi}_R = \alpha + \dfrac{\theta}{2} \\ \overline{\Phi}_S = \beta + \dfrac{\theta}{2} \end{cases}$$

Bar crossing angle

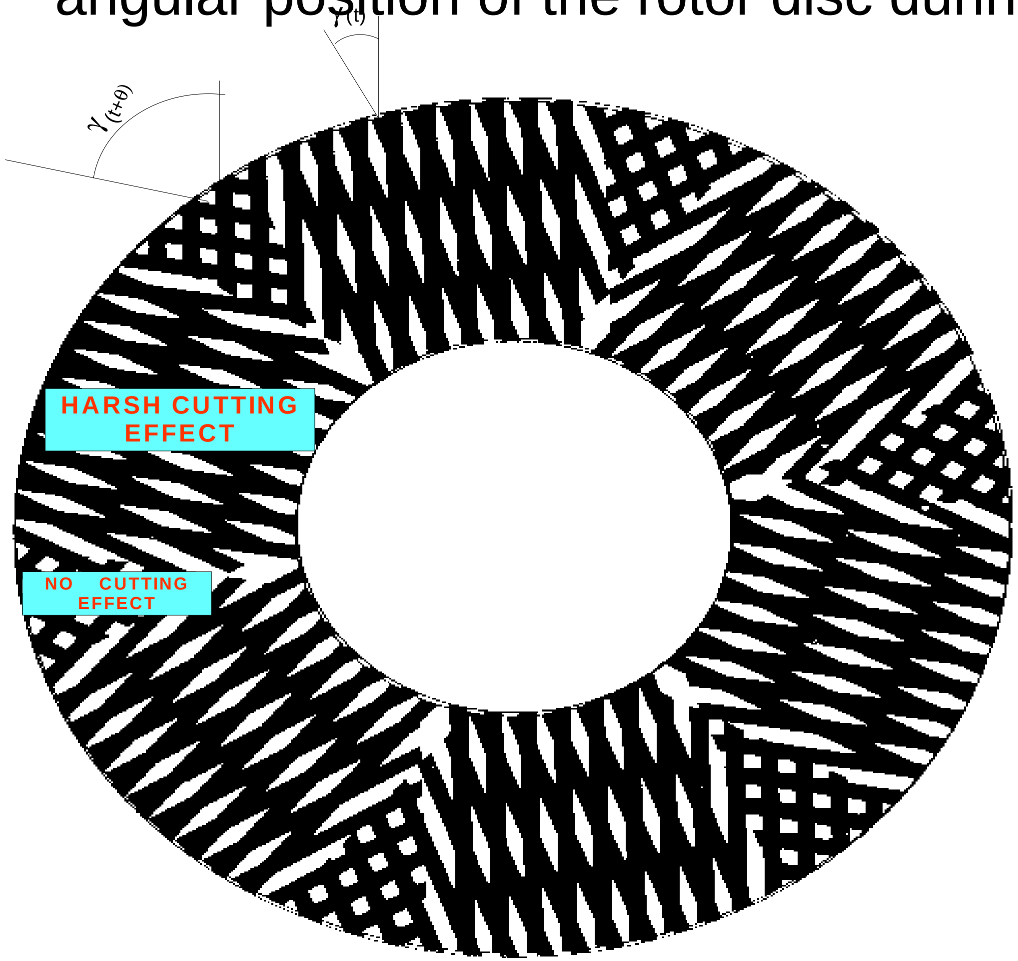
$$\overline{\gamma} = \overline{\Phi}_R + \overline{\Phi}_S = \alpha + \beta + \theta$$

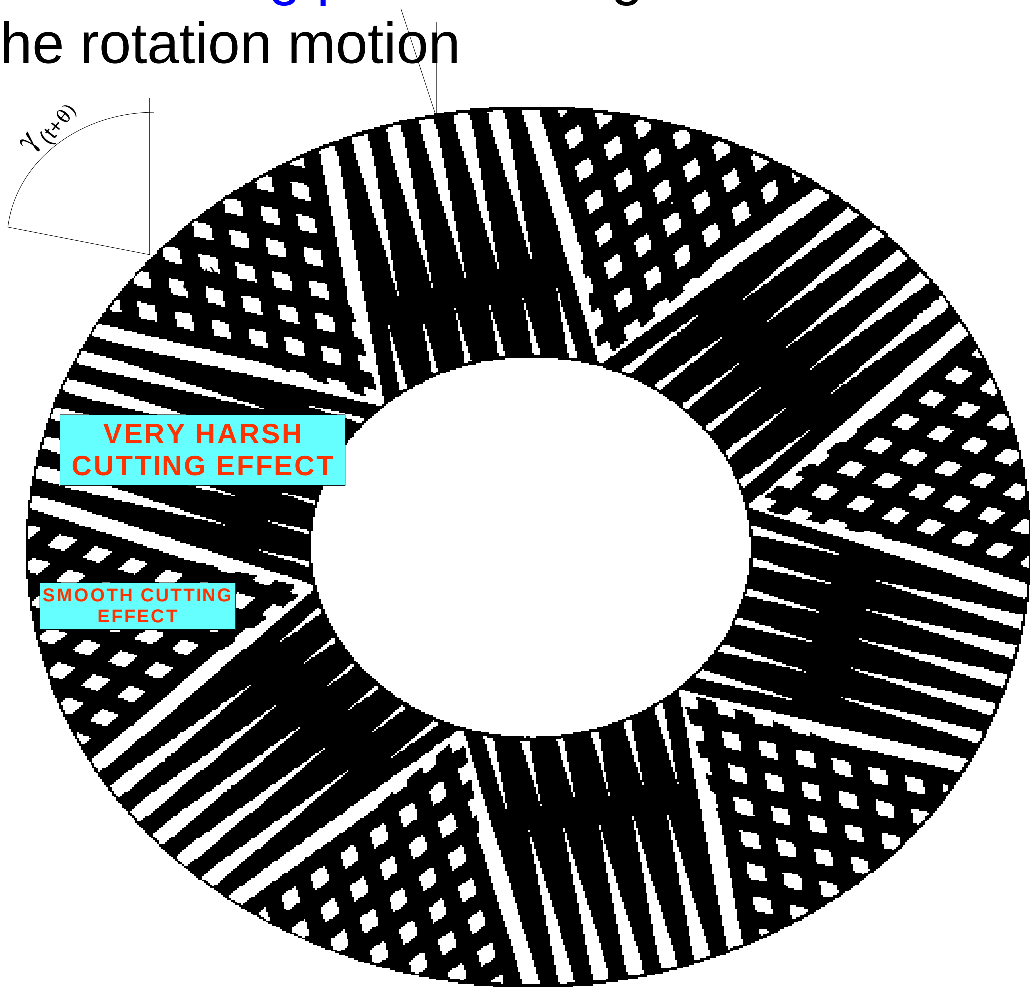
Relative motions of the surfaces : discs

N rotation speed (rev/s)

Superposition by transparency of a rotor disc in front of a stator disc .

The bar crossing angles and the number of crossing points change with the angular position of the rotor disc during the rotation motion





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Beginning with the net power and the sliding velocity

Brecht and Siewert (1960) introduced the Specific Energy Consumption, the net energy per mass of fibre (calculated as bone dry) from the definition of the loading B, given by Wultsch and Flucher (1958)

<u>How much energy is consumed</u> for the refining operation? > P net

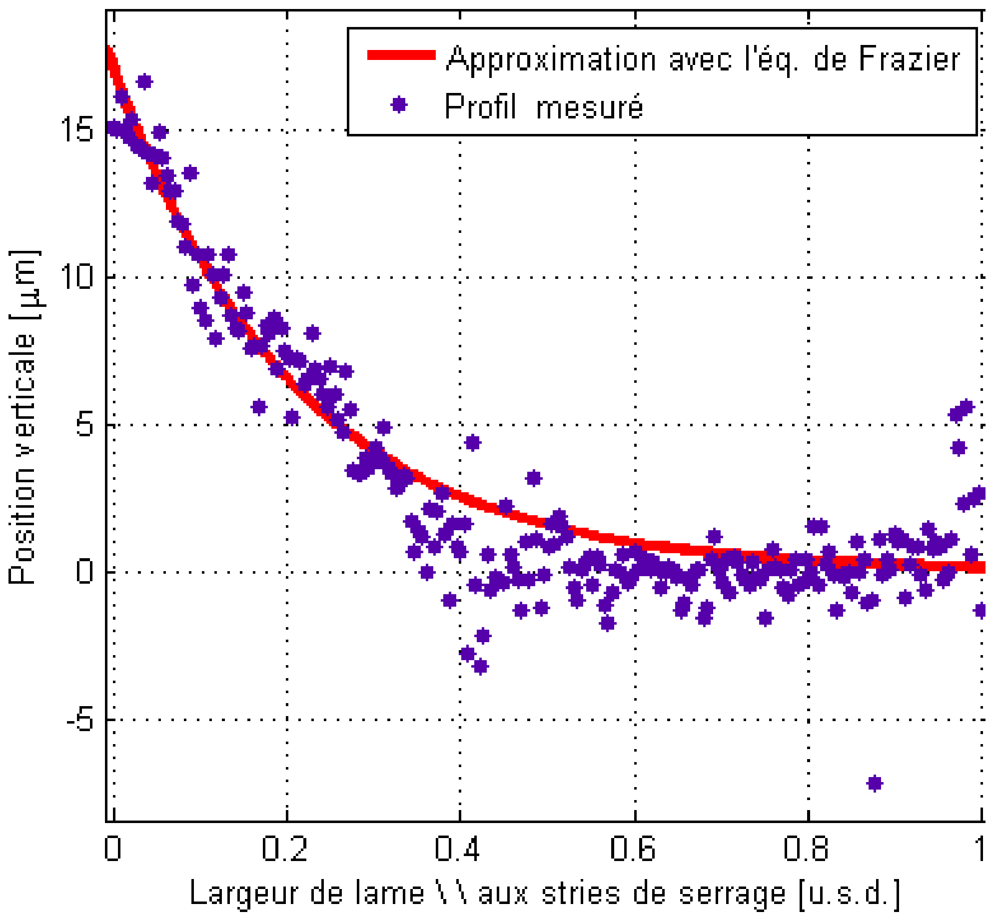
$$E_m = \frac{P_{net}}{Q.C_f} ; [kWh/T] \text{ or } [J/kg]$$

Bordin (2008, Ph-D thesis) developped the concept of average tangential velocity (or sliding velocity U) for the rotor disc → average radius < ρ > of the corona

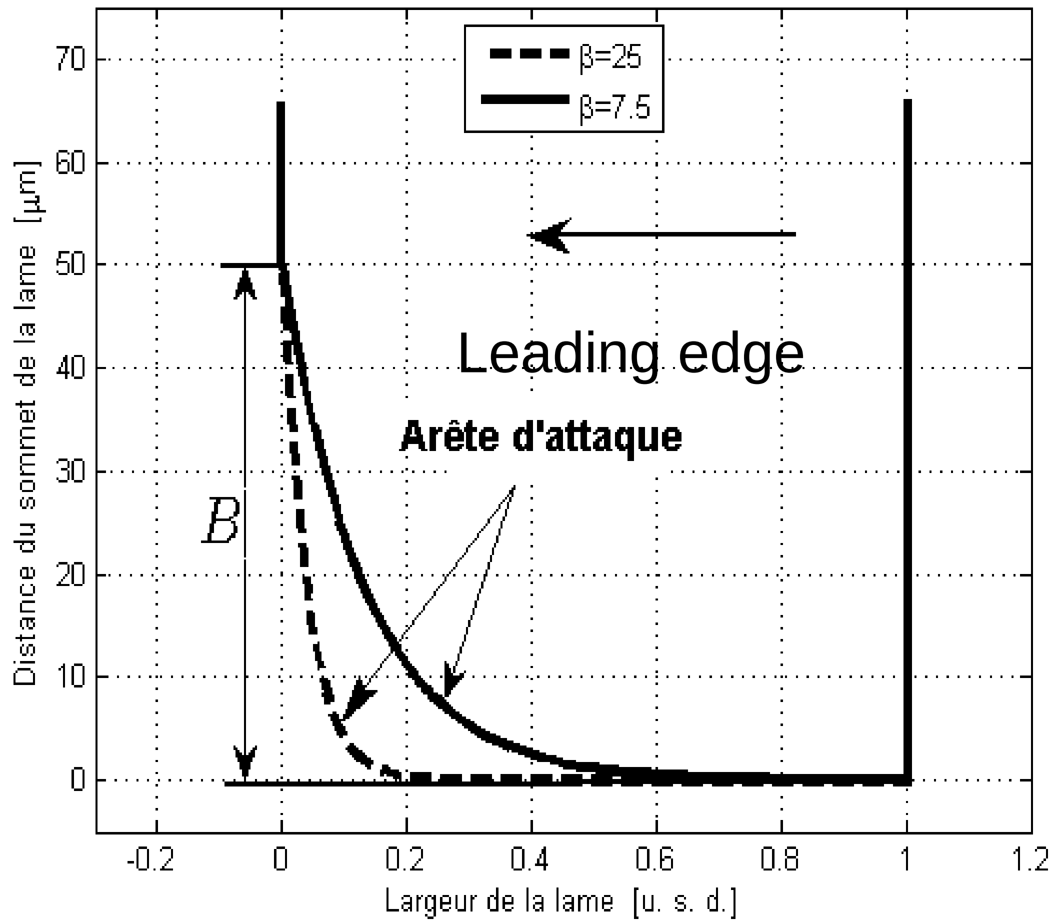
$$\text{For a radius } \rho : V_{tan}(\rho) = 2.\pi.N.\rho$$

$$< V_{tan} >= \frac{\int_{\rho_i}^{\rho_e} V_{tan}(\rho).2.\pi.\rho.d\rho}{\pi.(\rho_e^2 - \rho_i^2)} = \frac{4.\pi^2.N.(\rho_e^3 - \rho_i^3)}{3.\pi.(\rho_e^2 - \rho_i^2)} = 2.\pi.N. < \rho >= U$$

Quantification of the local wearing : measurements and modelling with the FRAZIER's equation



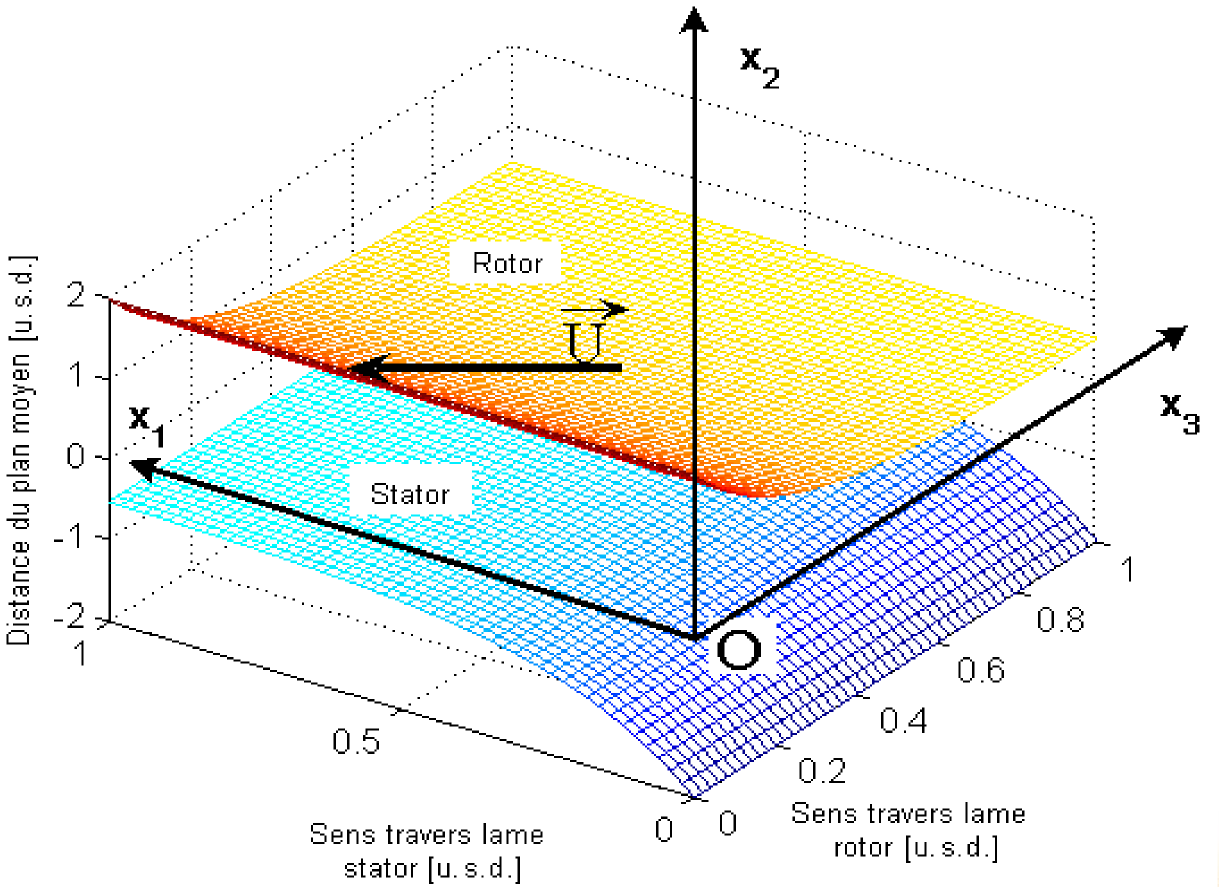
Bar width



Bar width

The net normal loading force and the global friction coefficient

Since Rance and Steenberg (1951), a refiner can be interpreted as a bearing load. Bordin (2008) modelled the average crossing point as a hydrodynamic bearing load considering the local geometry defined by the variables (gap, bar wearing, average crossing angle)



$$P_{net} = F_{net}^{tan}.U$$

$$f = \frac{F_{net}^{tan}}{F_{net}^{n}}$$

f is the global friction coefficient of the pair (metal, pulp suspension)

How to relate to refining fibre effects?

Roux (1981) proposed for the concept of « refining intensity »: the net normal (or net loading) force per crossing point

In 2009, this concept has been successfully extended to beaters, disc and conical refiners in a physical unified theory ;Ex: case of a single disc refiner

$$\frac{F^{n}_{net}}{< N_{CP} >} = \frac{SEL}{f.\sin(\alpha + \beta + \theta)}$$

$$SEL = \frac{3.(a+b)^2.P_{net}}{4\pi^2 N.(\rho_e^3 - \rho_i^3)}$$

This concept allows to answer to the question: how the SEC is consumed: what refining effects are induced on fibres? Cutting/fibrillation?

It is validated with the experimentations performed when the 3 angular parameters α, β and θ and the SEL parameters are modified and gives an understanding for the interpretation of the complex physical phenomena inside the confined zones in the gap clearance

Bordin (2008): experimental validation with the Stribeck's curve

Discs:

(3-3-4) +10°/+15° - AISI431

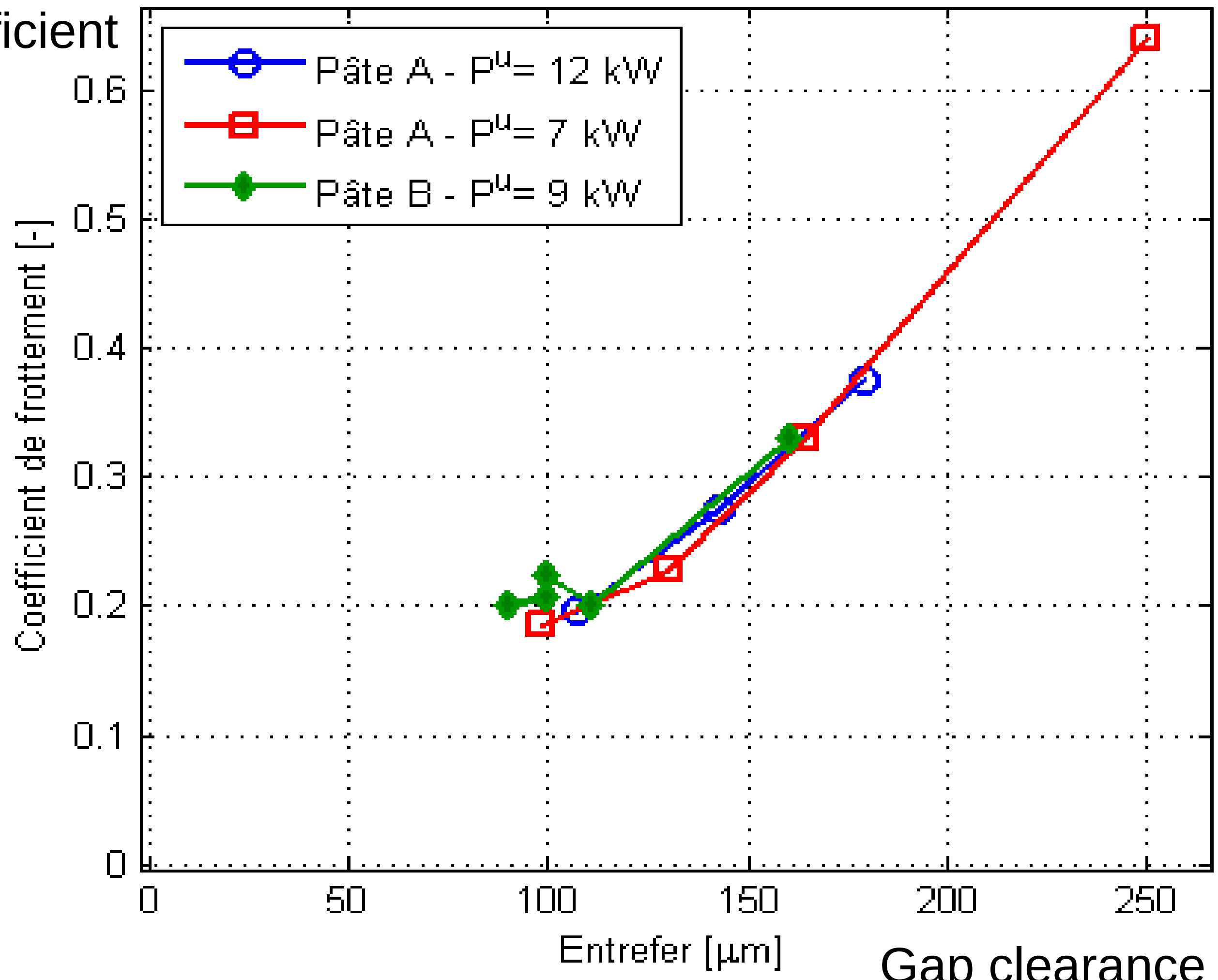
Pulp A:

Unbleached softwood Kraft

Pulp B:

Bleached softwood Kraft without fine elements

Friction coefficient



Gap clearance

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To summerize

f is a function of the gap clearance (known in lubrication theory as the Stribeck's curve)

The evaluation of any pulp property, influenced by the refining process, can be followed by the equation:

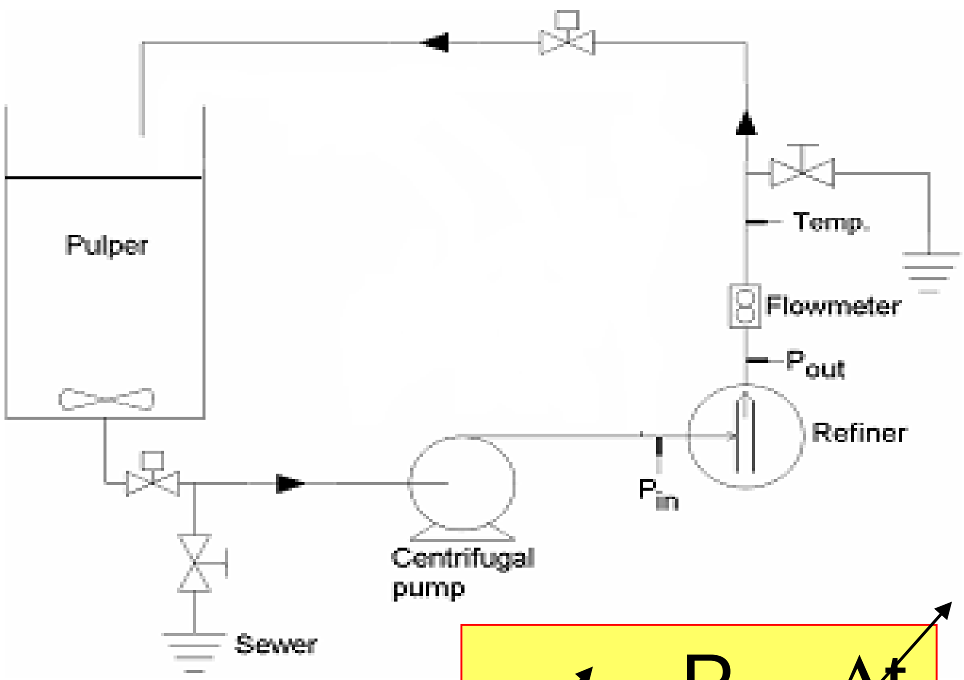
$$\text{Pulp Property} = F\,[E_m; RI; \bar{\gamma}; \text{wearing}; f; ...]$$

For a given local refining geometry and for a given wearing (bar and edge), the local forces can be determined.

Then, from the knowledge of the local geometry together with the force generation, the rheological properties of the pulp suspension can be evaluated

Conditions of trials performed on the installation

Refining installation - disc refiner and of the refining conditions for all the experimental trials performed in a batch mode (hydracycle conditions):



$$E_m = \frac{P_{net} \cdot \Delta t}{m}$$

<u>Constant conditions of trials:</u>

Solid mass fraction: C = 3.5%

Volumetric flow : Q = $10 m^3/h$

Rotation speed : N = 25 rev/s (or 1500 rev/min)

Net power : P_{net}

<u>Analysis of the shortening kinetics of fibres:</u>

Input : Net specific energy $\mathbf{E_m}$ (or time Δt)

Output: Average weighted Fibre Length = **Lf**

Parameter: a Refining Intensity : **RI**