

LOW CONSISTENCY REFINING PROCESS

THE STORY

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1. ABSTRACT

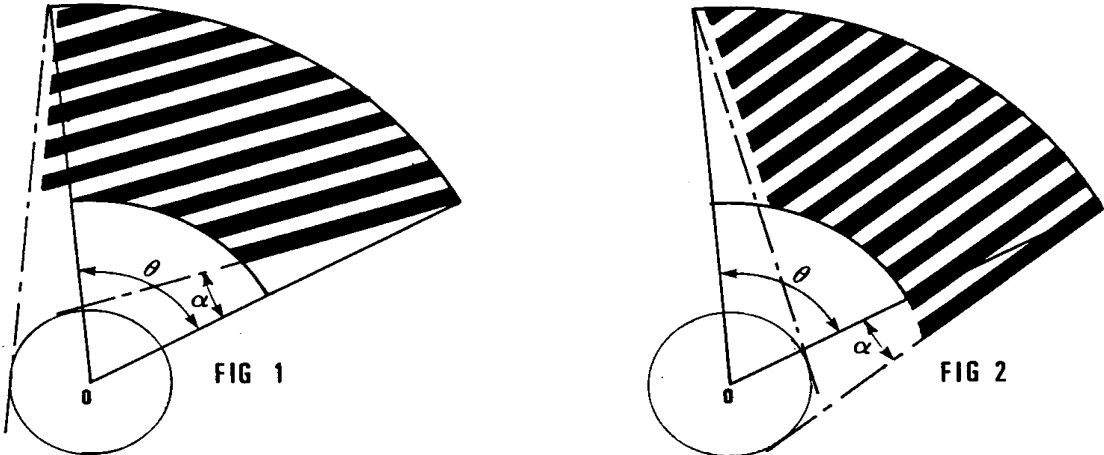
Actually, the story of the technique described here after started with comprehensive fundamental theories to build up mathematical models to fully describe the dynamic aspects of a rotor moving against a stator. From these pure analytical features, most classical topics described in literature as scalar parameters are now appearing as vectorial distributions that can be written under matrices. For each crossing point from any combination of rotor and stator patterns, one can determine the level and direction of energy impacts onto the stapled floc of fibers. Reciprocally, plate patterns can be designed from any matrix that represents energy transfer. This first step is a pure mathematical analysis called “**crossing points theory**“. On the other hand, pulp characteristics such as fiber lengths, freeness or slowness, hydration, gradient of dynamic viscosity, rate of flocculation,.. are supposed to be linked to the parameters described by the crossing points theory. The **bijjective diagram theory** gives a good mathematical approach from which every pulp characteristics can be accurately determined in relation with the relevant parameters given by the crossing point theory. To quantify some parameters, some refining trials on a pilot plant must be carried out. The pilot refining unit should also fit perfectly with the industrial data.

The papermakers are mainly interested by paper characteristics that can be extrapolated from the pulp characteristics, reference specific edge load and net specific energy consumption through non-linear multidimensional regressions. We confess that this technique is not exactly as much rigorous as the models given by the bijjective diagram theory for the pulp characteristics but this extension is a must and it works. Nevertheless, the results cannot be immediately transposed to an industrial refining unit. Numerous industrial parameters must be checked before the bijjective diagram technique could be applied. An expert system called CHECKDIAG has been developed to anticipate mechanical, electrical and hydraulic problems that can arise in an industrial refining unit. To make the technique fully reliable, any problem detected by CHECKDIAG must be solved. Finally, some extra parameters such as bar edge sharpness, metal grade, white water and chemical additives must also be taken into consideration. Transposition techniques are required to finally deliver any compromise of hand sheet paper characteristics versus freeness, energy consumption, plate patterns, applied power, throughput, ...

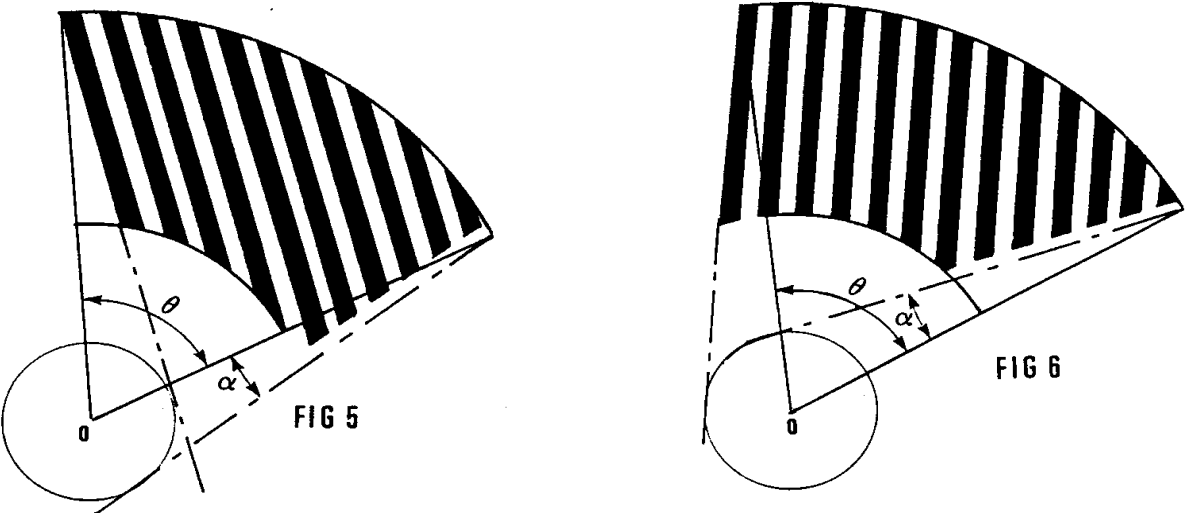
The story started in 1984. Our target consists in determining paper characteristics from pulp characteristics only through physical models. We have called for doctorate thesis to speed up our investigations.

2. HOW THE STORY STARTED

In March 1984, from the very first visits to French papermakers, many contradictions between the papermakers were immediately denoted and apparently the refining process seemed to be a deep mystery. The confirmation came first from Professor Charuel who was the director of E.F.P.G. (*University of Grenoble*) but who was also very keen to develop low consistency refining theories. Professor Charuel took the decision to invest a lot of money to buy refiner plates for the BLACK-CLAWSON 16'' of the school to study the effect of bar angles only. A one-year engineer project was established and Trioulere Daniel [2] has been selected to cope with this program. The geometrical aspects of the plates were considered. The positive and negative angles were first distinguished from their mirror images. Rigorously a positive angle cannot become a negative angle under the consideration of its mirror image. Rigorously right and left configurations mentioned by some plate manufacturers had no meaning. Thus, new definitions have been given to distinguish the four patterns governed by the same grinding angle with sectorial or pseudo-sectorial configurations. The figures 1 and 2 depict respectively a positive and a negative grinding angle both in a leading bar edge configuration.



The figures 5 and 6 depict respectively a positive and a negative grinding angle both in a trailing bar edge configuration.

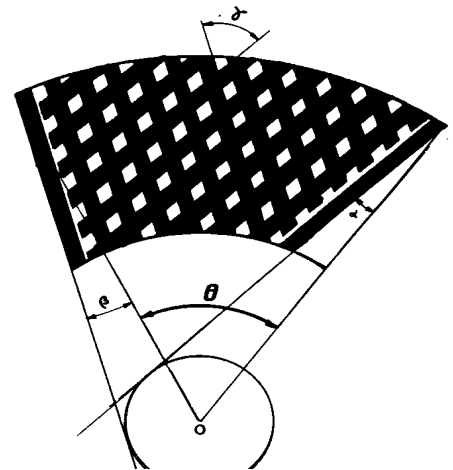


The E.F.P.G. bought many plates, leading and trailing bar pseudo-sectorial configurations, with the same grinding code (3-3-4) but with different grinding angles that was ranging from -20° to $+20^\circ$ with a pitch of 5° . This means a total of 32 plates from which 19 arrangements have been tried. Each trial was carried out in hydracycle under the same effective power, same flow and same pulp consistency. Two pulp grades were selected, a bleach kraft softwood pulp from southern pines and a bleached mix-hardwood. For each trial, 5 pulp samples were taken, which means that 5 levels of net specific energy were considered. Freeness, fiber lengths, WRV, and hand sheet paper characteristics have been measured. A total of 160 pulp samples were analyzed. Without this first investment, the bijective diagram technique should not probably exist nowadays. From this first work, the dynamic aspects of the plate became true. Nevertheless, we must yield to the facts that this rigorous aspect of plate pattern is not yet properly considered at industrial level even in France.

3. THE DYNAMIC ASPECTS

When the rotor moves against the stator, crossing points as depicted by the figure aside appears. Each crossing point is quantified by the bar angle γ sometimes called cutting angle. This angle depends on the relative position of the rotor in front of the stator. It has been demonstrated that this angle is a periodic function given by the equation:

$$\gamma(t) = \alpha + \beta + \theta + \frac{2\theta}{\pi} \sum_{k=1}^{\infty} \frac{(-1)^k}{k} \sin\left(\frac{k\omega t}{\theta/\pi}\right)$$



This equation, and the analysis of the results from the 160 pulp samples gave birth to a new fundamental concept called the effective cutting angle given by the root means square of the periodic function $\gamma(t)$. As a consequence of this first mathematical approach, it has been proven that the lower the effective cutting angle, the higher the cutting effect under the same conditions of effective power and net specific energy. Any attempt to obtain a similar relationship between the specific edge load and bar angles was a failure, whatever is the method to calculate the average length of the bars. Thus, the classical specific edge load formulas cannot be used for disc or conical refiners. A new technique should be built up. This was our conclusion in June 85. In October 1985 two engineer projects and a doctorate thesis have been started and the E.F.P.G made again big investments for plates. Thomas Pascal [3] studied the grinding codes and Maurel Pierre [4] studied the sector angles. Both works have been conducted with plate patterns from which the sum of the grinding angles was 0° that is $\alpha = +5^\circ$ and $\beta = -5^\circ$. Plates have been manufactured with the following grinding codes: (1.5-1.5-4) ; (2-2-4) ; (3-3-4) ; (4-4-4) ; (2-3-4) and (5-3-4). Ten arrangements from which 50 pulp samples were analyzed. Other plates were manufactured with sector angles of 15° , 20° , 22.5° , 30° , 60° and 90° . Eleven arrangements from which 55 pulp samples have been analyzed. From the results of the trials, the classical specific edge load formula has been definitely rejected. Instead we had introduced a reference specific edge load that was the specific edge load under $\alpha + \beta = 0^\circ$ and $\theta = 20^\circ$. The idea of virtual pattern and consequently

the reference specific edge load came later. Charuel decided to strengthen the field of researches and Professor Roux joined the team on 1st July 1986. Professor Roux [5] has determined in 1987, the general expression of the average number of crossing points in relation with the grinding code and the angular parameters. From this work, the gamma* formula have been discovered. This angle is a very close representation of the effective cutting angle given by:

$$\sin(\gamma^*) = \frac{\sin\left(\frac{\theta}{2}\right)}{\frac{\theta}{2}} \sin(\alpha + \beta + \theta)$$

4. FIRST APPROACH TO INDUSTRY

So far, this was a gentle but also a very fascinating work conducted by passionate people without economic interest. On Wednesday 25th June 1986 we have been invited by ATIP at Paris to make a paper about our researches. Most French papermakers were present in this event and the success was tremendous. Every papermakers want to optimize their plate patterns (*at this time we did not yet talk about refining unit optimization*) and everyone believed that great improvements could be reached in applying our theories. The bijective diagram technique has been achieved during the summer 1986. Actually, the word bijective came from the fact that it exists a bijection between a set of pattern parameters ($a, b, \alpha, \beta, \theta$) and a set of pulp characteristics ($^{\circ}SR, Lf, WRV$).

The technique consisted on achieving 6 trials in hydracycle mode to analyze 30 refined pulp samples (*To-day 5 trials with 25 pulp samples are enough*). To lower the quantity of pulp required for the trials, a 12'' single disc refiner was required and the CTP (*Paper Center at Grenoble*) was candidate to carry out the trials.

In October 1986, many pulp grades were analyzed on behalf of several French papermakers. In 1986, the papermakers were not yet crushed down under economic considerations and engineers were available to follow up our work and to sustain technical discussions. We immediately understood that our technique could not work properly without a close collaboration with the papermakers. Throughout the year 1987, eight refining studies at industrial level have been achieved (*CELLULOSE DU PIN, BANQUE DE FRANCE, PAPETERIES DE LANCEY, ARJO-WIGGINS ARCHES, PAPETERIES DE PONT-AUDEMER, LA ROCHETTE ALSACE, PAPETERIES DE PONT STE MAXENCE, EMIN LEYDIER*). Five papermakers have succeeded to improve their refining process with new plate patterns. Actually, we have been very lucky because we did not know yet that numerous industrial parameters could interfere with the results of our theoretical approach. Thank to these first failures and other ones later on, many industrial problems were diagnosed thank to the close collaboration with many French papermakers.

The transposition techniques and the diagnostics of an industrial refining unit are a must to anticipate any problem and to quantify accurately the paper characteristics. Usually when something wrong is done in a papermill, everyone knows it very quickly but in 1987 all French papermakers did follow up with us and most problems (*not all*) have been solved. From 1988 to 1990 included about twenty papermakers per year mainly in France call for this technique. This was an excellent opportunity to get a good industrial experience. The rate of successful industrial studies was increasing slowly but surely. During this period, many new industrial problems were discovered.

5. THEORITICAL DEVELOPMENTS ARE GOING ON

In October 1987, a new project engineer at E.F.P.G. started by De Agostini Frederic [6] who confirmed some key points of the bijective diagram theory. On Wednesday 28th September 1988 we got a scientific reward in return for our developments about the low consistency refining process. The same year we got also another reward in return for the fruitful collaboration between a university and a private company. Then, in October 1988 Brissaud Jean-marc [7] started a project to study the influence of dams in low consistency refining process. Some trials with negative grinding angles have been extended to - 45°. Even under big negative angles, the fiber cutting effect remains accurately described by the γ^* or γ_{eff} laws. In March 1989, the concept of virtual pattern has been developed that gave birth to another concept: **the reference specific edge load** given by the formula:

$$S.E.L._0 = \frac{3.P_{eff} \cdot (a_R + b_R)(a_S + b_S)}{4.\pi^2 .RPS.(R_o^3 - R_i^3)}$$

The diagrams could now be scaled versus SELo and γ^* . We got a MATLAB license and the program FIBROLOGIC was written in late 1990.

Another work at E.F.P.G. in 1989 has been undertaken by Chaussy Didier [8] who placed sensors in stator bars to measure the pressure impacts. Spectral analysis in relation with the refiner clearance and the plate patterns were analyzed. The fundamental studies of the micro-energy transfers at crossing point level were started. To validate the relevant equations, some portions of bars in between coronas have been machined one millimeter higher to study the refining process within a small area without disturbing the flow of the pulp inside the refiner. A new Engineer project was started in October 1989 by Scheidecker Eric [9]. The equation of the rotor bar sliding velocity against a stator bar was established and the idea of curvilinear bar patterns was coming up. For any crossing point located on a polar radius ρ we can prove that:

$$v = \frac{\omega \sqrt{\rho^2 - \rho_o^2 \sin^2 \alpha}}{\sin \gamma}$$

where ρ_o stands for the inner radius of the disc and α for the grinding angle of the rotor.

From this equation we can see that the role played by α is different from β .

Actually, papermakers are using the same pattern for the rotor and the stator to avoid extra costs from models but also to ease the work of the maintenance people. For conical refiners, rotor pattern is usually different from stator one but it is also difficult to mistake the rotor from the stator. The refiners remain the dirty and noisy machines and no one is prepared to face some light difficulties even when better refining conditions could be obtained.

6. NEW CHALLENGES AT INTERNATIONAL LEVEL

In October 1991 another engineer project was started by Cena Simon [10] who carried out many trials on high yield plates, that is curvilinear patterns. The results were fantastic. The trials have been carried out on a 16'' double-disc from BLACK-CLAWSON under 1177 RPM and under effective powers ranging from 40 kW to 10 kW **only**. Eighteen refining trials

were achieved that makes a total of 80 pulp samples to be analyzed. From these trials and in keeping with the theory, about 20% energy saving was obtained to reach a higher tear and tensile index under the same level of freeness. These high yield plates were completely silent and lifetime should theoretically spoken be infinite. Nevertheless, the axial force on the refiner is four times higher under the same applied power compared to classical plates and the hydraulic capacity of the refiner was lowered. These plates could not **honestly** been proposed to the papermakers because of the risk to damage their refiners. In late 1991 a tester called FIBROPTRONIC 3000 was developed to measure fiber length distributions but only two papermills in France (*CLAIREFONTAINE and CDRA*) were interested. For financial reasons, we gave up and the license has been taken over by a Canadian company. This tester was very successful in North-America. Nevertheless, the attached program dedicated to compare fiber length distributions has never been granted. Fiber length testers deliver histograms only. To estimate cutting effects, papermakers simply compare the histograms what is mathematically not valid. Furthermore, these comparisons could easily be very long and tedious. True comparisons consist in turning the histograms into densities of probability and through convolutions one can determine the relevant density of probability that really permits to quantify very accurately the cutting effect of fibers. Unfortunately, no one is interested by this technique from lack of the required mathematical background.

Starting 1992 a deep economical overturning arose and papermakers were less and less available to talk about technique. During this period, our program FIBROLOGIC has been properly developed and Professor Roux gave a physical meaning of the reference specific edge load given by:

$$\frac{SEL_0}{\sin(\gamma^*)} = \frac{f F_n^u}{\bar{n}}$$

where F_n^u stands for the normal effective force, f for the friction factor and \bar{n} for the average number of crossing points. On our side, we have extended the concept of effective power to a distribution that can be written:

$$P_{eff}(\rho, t) = \frac{3k \left[\left(\frac{\rho}{\rho_a} \right)^2 - k^2 \right]}{1 - k^3} \cos[\gamma(t)] e^{\frac{\omega}{\psi} \ln[\sin(\gamma(t))]} \bar{P}_{eff}$$

and consequently to the reference specific edge load $SEL_o(\rho)$ as a distribution.

This distribution shows that the specific edge load is not uniformly distributed versus the relevant crossing point. To get uniform distribution two requisites must be obtained.

$\gamma(t)$ must be maintained constant and this is possible only with spiral logarithmic bar patterns.

ρ must be constant what is not possible with a disc refiner.

From this equation, came the idea of the cylindrical refiner but once again for financial reasons we let the idea in our files.

Nevertheless, uniform energy transfer does not mean better refining treatment. A sample of pulp consists on a very heterogeneous matrix of fibers that cannot be individually sorted out to get selected treatments. Is it better to homogenize a heterogeneous matrix or to heterogenize it to get a matrix as much homogeneous as possible? Is homogeneity means better paper characteristics?

Curvilinear patterns on a cylindrical refiner could be a good alternative to reach some specific compromises of paper characteristics but nothing more.

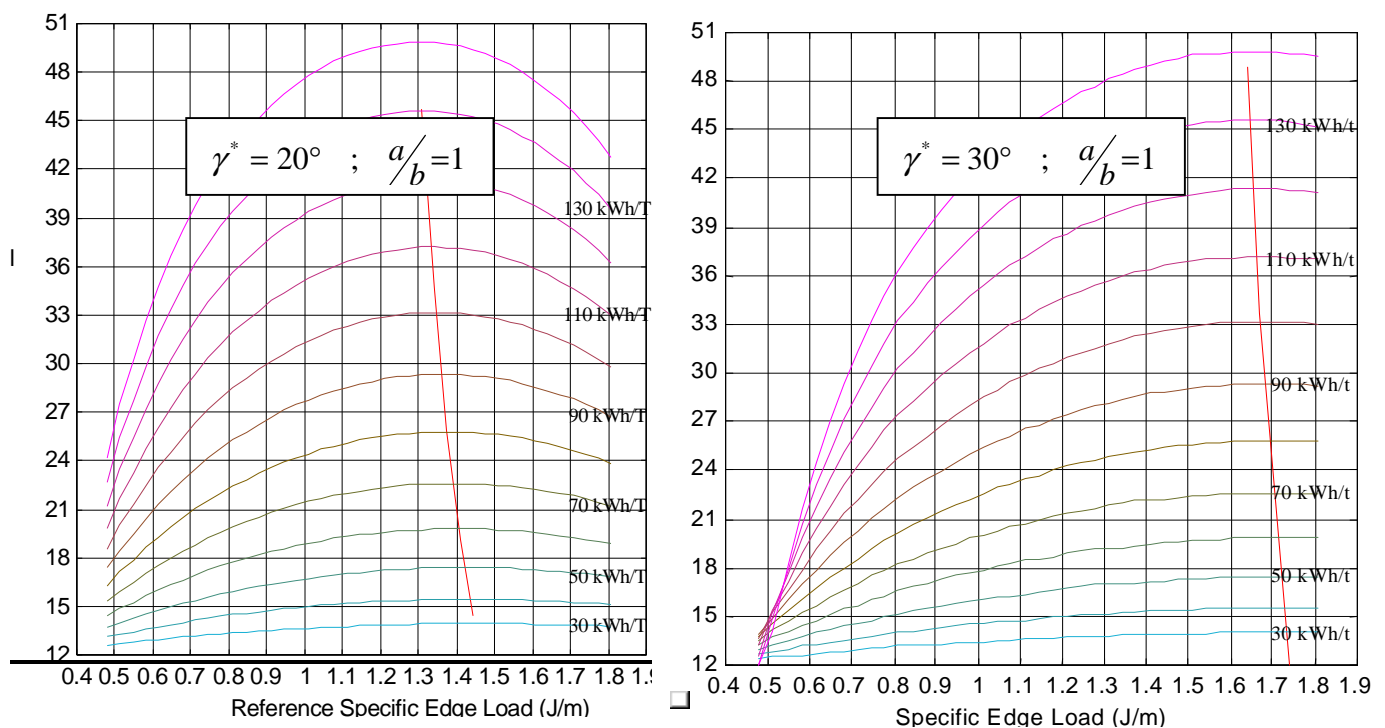
Under low Canadian freeness (or high °SR) we should find some advantages.

From 1993 to 1995 a doctorate thesis sustained by Mayade Thierry [11] was mainly focused on the high yield plates.

During this period of time, we got some demands for pulp studies mainly from United-States. The rate of failure was henceforth very low (*less than 10%*) because the necessary steps regarding diagnostics and transpositions of the results from a pilot to an industrial refining unit were taken into consideration. The technique also works with the conical refiners, but the

$$^{\circ}\text{SR} = F(\text{SELSR}, \text{KWH/T})$$

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influence of the bar angles is as much less as the cone angle is low. Under the same specific edge load, depending on bar angles wide dispersion of paper characteristics could be anticipated with a disc refiner. Let us compare the bijective diagrams $^{\circ}\text{SR}(\text{SELo}, W)$ of a UBKP respectively for γ^* equal 20° and 30° . This is a difference of 10° only what is low compared to the potential range $[0^\circ; 50^\circ]$. Beyond 50° the risk of plugging is very high.

Under a reference specific edge load of 1 Ws/m and a net energy consumption of 120 KWH/T for example, the expected slowness should be 39°SR or 35°SR depending on whether $\gamma^* = 20^\circ$ or 30° . The dispersion with double-disc refiners reaches 10% (*less than 3% with JCO refiners and 5% with CLAFLIN refiners*). If papermakers would accept to cope with four different patterns instead of two for double disc refiners, about 10% of extra energy consumption could be saved.

In the same period, another doctorate thesis was started by Radoslavova Dessislava [12] about the hydrodynamic parameters of the refining process.

7. NEW AND FASTER DEVELOPMENTS

During the year 1999 the technique of pulp grade optimization was developed. A new data program called PULPDIAG has been written on a MATLAB base. This program has been successfully used for one papermill in Europe and one in Chile. Money savings were very high and paid back time for the study was less than one month.

Since 2000, a new tester to measure the dynamic freeness of any pulp grade is under development. This tester has been exhibited for the first time at IP2001 in France but no one came to see it. Papermakers are very conservative and they stick on their classical and antic measures of °SR or CSF. We made a paper about this laboratory apparatus called DFT3000 at Stockholm [14]. Dr. CURTIL [15] who has his M.A.Sc. in electronic and who is specialized in the field of sensors joined the team during the year 2001 and he is really doing very good work for our company.

In 2001, our CHECKDIAG program was widely extended and turned into a Labview version. In 2002 the technique of the virtual refiners (*not to be confused with virtual patterns*) took birth.

The technique consists in substituting progressively refiners in series by a virtual refiner that represents exactly the first two, then the first three,... refiners.

In so doing, only one refiner whatever is the number of refiners in the line is considered.

8. PILOT PLANT

In 2002 we got a demand from a big foreign pulpmill to supply a pilot plant to deal with FIBROLOGIC and PULPDIAG. The pilot plant plays a fundamental role. The refiner must operate in the optimal conditions throughout the trials and reference specific edge loads must be suitably selected versus pulp grades. The plates must perfectly match each other and a wide range of pulp characteristics must be obtained. Pulp sampling is another important problem. The relevant specific energy calculated by the control desk for each pulp sample must be a true representation of the sample. Two pulp samples must be taken for each cycle to determine a self-control of the assigned net specific energy. The no-load power must be accurately measured which is not possible with a classical single disc refiner because the stroke is not long enough. The discs must be parallel without any deformation and dilatation from temperature must be taken into consideration. The clearance must be under control, the bearing must accept very high axial forces compared to a classical refiner. Sensors are implemented to control the axial force and the clearance. The tank and its impeller must be shaped to reach a homogeneous distribution of the refined pulp. The hydracycle system must be a true representation of refiners in series. An attached program delivers for each trial the sampling times and the relevant net specific energies. In so doing, only conditioned matrices are involved in the process. Then came further orders for pilot refiners from 2003.

9. CONCLUSIONS

In 1984 we started a fruitful collaboration with the E.F.P.G. [16] and our turnover was growing very fast because at that time the French papermakers were very anxious to save money from their refining units. In 1997, Professor Roux [17] gave a physical meaning to the

bijjective diagram technique Starting 1998, most French papermakers had to face new production targets and deep restructurations took place.

MATECH EUROPE is not a big company and consequently it is really very difficult for us to promote our technique against most big manufacturers who do not like to hear about many refiners being definitely stopped.

In France came a new generation of young Engineers with new methods of work. To-day, mainly statistical methods are being considered. Just click on your computer and you get the solution of your problems. No need to understand. What a nice mess !

Many other papers have been issued [18]. Some are now translated into many languages. One paper [19] have been published in Japan.

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製紙技術に関わる人のために

—リファイナーの問題点と最適化の方法—

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