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APPLICATIONS OF RECYCLED PAPER MILLS EFFLUENTS TO WOOD SUBSTITUTIVE PRODUCTS (RESPRO): EXECUTIVE SUMMARY

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Resumen

Este artículo es una síntesis del informe técnico final del proyecto "Empleo de efluentes reciclados de papeleras en productos sustitutivos de la madera –RESPRO-"que fue financiado por la Comisión Europea dentro de programa Brite/Euram. El proyecto aumentó las alternativas de gestión de los lodos primarios de depuradora generados en empresas de pasta y papel. En particular, incrementó aquellas alternativas no destructivas relacionadas con el reciclado de estos residuos en el sector maderero y con la reutilización de lodos en la propia industria de la pasta y el papel. El principal objetivo del proyecto fue estudiar la viabilidad técnica de estas alternativas a un nivel precompetitivo.

***Palabras clave**: Reciclado, Reutilización, Lodo primario, Pasta y papel.*

Summary

This contribution is a synthesis of the final technical report of the project "Applications of recycled paper mills effluents to wood substitutive products -RESPRO-" which was funded by the European Commission under the Brite/Euram program. The project increased alternative management of primary sludge from pulp and paper mills. Particularly, those non-destructive alternatives related to the reutilization of sludges in pulp and paper industry and to the recycling of this waste in the wood sector. The main objective of the project was to study the technical feasibility of these alternatives at a precompetitive level.

***Key Words:** Recycling, Reuse, Primary sludge, Pulp and paper.*

Introduction[1]

Pulp and paper mills generate a great volume of waste water. Most mills use primary sedimentation clarifiers to remove suspended solids from waste water (primary treatment) and, in some cases, a type of secondary biological treatment to remove biological oxygen demand –BOD– (secondary treatment). These systems generate solids that are dewatered into a sludge that requires disposal. In a dry basis, primary sludges represent a 4-20 % of the end-product (Scott and Smith, 1995). It has been estimated that the European pulp and paper industry has generated more than 3000000 ton of primary sludge during 1995. These wastes have been classified by the European Commission with the code 030300 (from 030301 to 030307, for the more common wastes, and 030399 for unclassified wastes) (Environment-Agency, 2002).

Pulp and paper mills use mostly wood, water and papermaking fillers as raw materials. Although most of these mills minimise losses from the process, a great volume of waste water is generated. The major sources of effluent pollution in a pulp and paper mill complex are the following critical phases (EPA, 1995; Smook, 1982): Water used in wood handling and barking; digester and evaporator condensates; white water from screening and cleaning; bleach plant washer filtrates; paper machine white water; fibre and liquor spills from all sections; inks, fillers and detergents from deinking processes

The two main methods employed in the pulp and paper industry for clarifying effluents are gravity sedimentation and dissolved-air flotation.

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Sedimentation or gravity settling is by far the most common process used, since it is relatively insensitive to variations in flow and solid concentration and requires little attention and maintenance. Flotation processes are generally more efficient in removal of solids, but are more expensive to operate.

Traditionally, the dewatering operation has been carried out as a two-stage process, utilising filtration or centrifugation as the first stage (up to 15 to 25% solids) followed by pressing with a V-press or screw press to achieve a final solid content of 35 to 40%. Because of the rise in price of the transportation systems, more interest is being shown currently in equipments such as pressure filters or moving belt presses, which are capable of taking sludge and thickening it directly to 40 to 45% solids in one operation. The two main factors that are being taken into account to choice the most adequate equipment are the initial solid content of the sludge and its dewaterability. Generally, primary sludges are relatively easy to dewater, whereas biological sludges are extremely difficult. In some cases, a vibrating screen is used to dewater sludges having a high drainability.

Paper industry sludges frequently contain significant percentages of both cellulose fibre and papermaking fillers, such as clay, $CaCO_3$, and titanium dioxide. The primary way of disposal for this type of sludge has been land application and landfilling (Pridham and Cline, 1988). However, with landfill space becoming increasingly scarce, some sludges are being burned or incinerated to reduce the volume and to recover part of the energy (Diehn and Zuercher, 1990; James and Kane, 1991; Kraft and Orender, 1993; Linderoth, 1989). Biological and physical-chemical treatments have also been considered (Gillespie, 1987; Rodriguez-Jimenez *et al.,* 1990). The most widely research area of alternative solid waste management has been the use of various wastes as feedstock in the manufacture of building materials such as cement, bricks, ceramics, and concrete (Hardesty and Beer, 1993; Thomas *et al.,* 1987; Wiegand and Unwin, 1994; Zani *et al.,* 1990; Zani *et al.,* 1991).

Attempts have been made to reduce sludge volume by reclaiming the fibre and/or filler in sludge for reuse within pulp and papermaking processes (Scott and Smith, 1995). The equipment used to separate fibre or filler from sludge may be as conventional as screens and cleaners, or more elaborate such as wet air oxidation (Wiegand, 1993). The most common technique for reclaiming fibre from sludge is to recycle primary sludge back into the fibre processing system of the mill. This technique is commonly used by recycled paper-board mills and by some manufactures of unbleached and bleached pulp and paper (Rosenqvist, 1978). Some systems utilize sludges from the primary clarification of wastewaters which contain higher amounts of fibre. Effluents from paper machines bleach plants, and various cleaning and screening operations are targets for fibre reclamation. Other wastewaters such as those from wood handling or chemical recovery systems usually contain nonfibrous contaminants which can become problematic in fibre recovery systems unless cleaning systems are employed. Bark, lime solids, dregs, grits, and dirt are some examples of contaminants which are avoided when possible.

The reuse of sludges in pulp and papermaking processes is not always available since sludge can decrease the quality of the final product. The project "Applications of recycled paper mills effluents to wood substitutive products -RESPRO" is mainly focused to determine the feasibility of reuse sludges in wood and paper industrial sectors where the sludge does not modify the quality of the final product.

The aim of this project has been to reuse primary sludges in the paper and cardboard industry and to recycle them in the wood sector. We assessed the feasibility of both waste management alternatives at a pre-competitive level. At the same time, a secondary objective was to identify and develop those other industrial applications that are currently carried out using sludges as raw material and can be utilized by the project partners, specially the industrial ones.

Methods and organization

Humidity, Ash content, Schopper-Riegler (ºSR) and pH of pulp and sludges were analyzed following standard methods (Ochoa de Alda, 2007). Abrasivity of sludges (g/y, weight of steel worn out in one year) was estimated using a valley abrasion tester (Gill *et al.,* 1982). Oxygen uptake was measured in a BOD_5 apparatus. Handsheets preparation, and tests for paper and board applications were performed following standard methods (Ochoa de Alda, 2007).

Medium density fibreboards (MDF) were manufactured using sludge as raw material by adapting the industrial process for MDF production to a laboratory scale. Sludges were dried and the resulting fibres were prepared for urea-formaldehyde resin binder addition. A fibre mat was formed and pressed following tree different methods: Dry pressing (70 kg/cm^2 at 220ºC for 2.5 min), mid dry pressing (60 kg/cm^2 at 170ºC for 5.5 min) and humid pressing (50 kg/cm^2 for 30 s followed by 10 kg/cm^2 for 3 min, and finishing applying 50kg/cm^2 for 2.5 min). Resulting boards were tested using standard methods UNE 56.719.86 (specific gravity), UNE 56.771.71 (bending strength and modulus of elasticity) and UNE 56.723 (formaldehyde emission).

Organization

Research work was organized in tasks to cover the following objectives:

1. Sludge characterization to identify sources of information which must be value to pursue particular alternatives, i.e. fibre content and quality, ºSR, humidity, etc.

2. Identification of sludge applications, and selection and mixing of sludges for particular applications.

3. Identify preprocessing problems which must be consider for reutilization and recycling of sludges.

4. Identify the critical factor that determine sludge upgrading, and design and construct a prototype to obtain raw material from sludge.

5. Determine requirements, through standard methods, for each different application.

6. Identify the legal frame in which applications must be developed.

7. Demonstrate, at a laboratory level, those applications that can be properly carried out (following the methods described in the objective 5).

8. Perform industrial trials of the applications.

In order to achieve these objectives, research work coordinated and unified the activities of 4 research centres expertise in:

• pulp and paper technology (Escuela de Ingeniería Papelera, Tolosa, Guipúzcoa, Spain)

• wood and resins technologies (CIDEMCO, Azpeitia, Guipúzcoa, Spain)

• dewatering and drying systems (KVÆNER Eureka, a.s, Norway)

• managing and coordination of research projects as well as waste management activities (GESTEP S.L., Aduna, Guipúzcoa, Spain)

• Research work was carried out as described in the original project with slightly modifications (Fig.1).

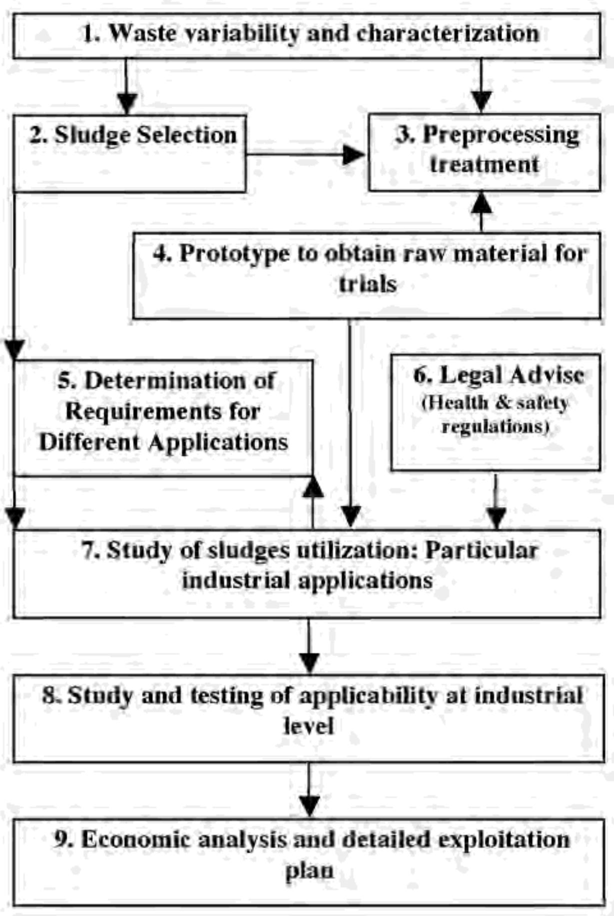

Figura 1. RESPRO project flow diagram.

Results and discussion

1. Waste variability and characterization

Out of the 38 European pulp and paper mills enquired, 22 of them permitted us to sample and characterize their primary sludges while 16 did not generate sludges in the required conditions. Together, these pulp and paper mills generated a total annual output of dry sludge of 121100 ton. Although this amount represented only a 4% of the European production of sludge, pulp and paper processes of these mills are representative of the most commonly used in the pulp and paper industry. Sludges were obtained from 1 mechanical pulp mill, 1 mechanical bleached pulp mill, 8 bleached Kraft pulp mills, 3 integrated Kraft pulp and paper mills, 3 integrated bleached Kraft pulp and paper mills, 3 paper mills and 3 recycling paper mills. During sampling, we identified critical points where the wastes were generated (dekers, fibre recovery systems, etc). Sludges from mechanical pulp mills were mainly composed by fibres whereas sludges from paper mills and recycling paper mills are mainly composed by paper making fillers and variable amounts of fibres and additives. Kraft pulp and paper mills showed a great variability in sludge composition due, in most cases, to the efficiency of the chemicals recovery system, which modified the inorganic content of sludges (mainly CO_3Ca).

Fibre content and quality, humidity and ash content were the most important characteristics of sludges that we studied since these parameters determined by-product applications and cost. For this purpose, a sludge fractionation procedure was designed to quantify fibre and to study fibre length, fibre length distribution and drainability of the purified fibre. The same procedure allowed us to estimate the yield we could obtain at industrial level (Ochoa de Alda, 2007).

Sludges showed a wide range of humidity 65±17, (average ± SD). Variability depended on the method used to clarify and dewater sludges, and the presence of chemicals (polyelectrolytes) used to aid dewatering processes.

Statistical distribution of the ash content divided sludges into two types, low-ash (<20% w/w) and high-ash content (>30% w/w), whereas statistical distribution of fibre content permit to classified sludges into low fibre (<60% w/w) and high fibre content (>70% w/w). As a result, sludges were classified into 4 types depending on the relative ash and fibre content. Finally, the fibre quality was accurately determined. One of the most innovative results of the task 1 is that, in some cases, the length distribution of fibres from sludges can be compared to standards (*Eucalyptus* and *Pinus*) and that fibre drainability (ºSR) were, in principle, appropriate to use recovery fibres into pulp and paper mills products.

Conclusions of task 1: 1) this task increase non-conventional solid waste management alternatives and identify sources of information which may have value for those wishing to pursue a particular alternative. 2) With the exception of sludges originated in mechanical pulp mills, the sludge characteristics can not be inferred from the industrial processes in which is generated.

Pulp and paper mills showed a high variability in the sludge production, humidity, ash and fibre contents. In most cases, for a given mill, variability of these parameters was low in a time course. 3) Fibres from most pulp and paper mill sludges could had a high quality to be employed in paper and cardboard applications. 4) Ash and fibre contents appear to be the most appropriate variables to classify sludges for a further application.

2. Sludge selection

Firstly, a tentative management program was designed for each type of sludge resulting from task 1. Reuse of **type I sludge (high-fiber and low-ash contents)** in paper products could be feasible at several board mills where the cleanliness of the furnish was not critical (Scott and Smith, 1995). **Type II (low-fibre and low-ash contents)** could be used in wood substitutive materials either alone or mixed with type I. Although, type I and type II sludges are the objectives of the project, they only represent a 13% of the total output of dry sludge. Thus, tentative management programs were designed for **type III (high-fibre and high-ash contents)** and **type IV (low-fibre and high-ash contents)** sludges. Type III could be used as feedstock in the manufacture of cementitious composites (Karam and Gibson, 1994; Thomas *et al.,* 1987). Type IV could be utilized in the manufacture of building materials such as cement (Diehn and Zuercher, 1990), bricks (Andreola et al., 2005; Cernec *et al.,* 2005), ceramics and concrete (Chun and Naik, 2004). Mixed with type III, type IV can be employed in the production of lightweight aggregates. Sludges from paper mills and recycling paper mills could be applied in landfill technologies i.e., as landfill barriers to avoid mixing of wastes (Gellman, 1989; Gellman, 1990). In this sense, type I and II sludges could be used as part of landfill sealing covers to restore soil (Blosser, 1984; Blosser, 1986; Das *et al.,* 2002; Jordan and Rodriguez, 2004; Taylor *et al.,* 1983)

A preliminary economic evaluation was carried out looking for eventual consumers in the surrounding area (150 km, since transport, and hence humidity, is the critical factors for further applications) resulting that the above mentioned management program could be feasible close Tolosa (Guipúzcoa, Spain), where exits a high concentration of pulp and paper mills.

Homogeneous mixing of sludges is a prerequisite to obtain a given type of raw material. Sludges mixing must be done at the humidity provided by mills (or higher) since, when dryed, high-fibre content sludges seemed a fluffy material difficult to disentangle and to handle, whereas high-ash content sludges aggregated in small particles.

Conclusions of task 2: 1) from a theoretical point of view all sludges can be ascribed to a solid management program. 2) Most of the suggested applications can be carried out in the surrounding area of Tolosa. 3) Sludges must be mixed at the humidity provided by mills, before drying process. 4) Mixing was beneficial to obtain a pH close to 7.

3. Preprocessing treatment

The third task was dedicated to study factors that could limit the installation for raw material generation and processing. In principle, toxicity, pH, abrasivity and microbial degradation were considered critical factors together with water content of sludges. A revision of the scientific literature about toxicity of sludges indicated that these solid wastes are not toxic in general, although this must be clearly specified for each application (Larsson *et al.,* 2002; Rantala *et al.,* 1999; Rantala *et al.,* 2000). On the other hand, pH of aqueous extracts were not corrosive, 7.6±1.3 (av. ± SD) and abrasivity of sludges (11±8 g /y) were far from mineral standards, which abrasivity (140-180 g/y) is recognized to affect durability of drying systems. O_2 uptake of sludges showed a wide statistical distribution being the average 47±49 μgO_2 g^{-1} dry sludge h^{-1} (av.± SD). This indicated that near 6 % (w/w) of sludge can be degraded in 1 month, since it is estimated that 0.59 g of O_2 are uptake when 1 g of cellulose is aerobically degraded.

For most applications sludges must be dewatered and/or dried. In fact, sludge upgrading is limited by the drying cost. From a theoretical study, (evaluating initial and final moisture content, the requirement of chemicals, the running costs and the investment), it was concluded that the most appropriate dewatering methods was the screw presses, a dewatering method already employed by a lot of pulp and paper mills to avoid unnecessary transport of water to the landfill (Chen *et al.,* 2002). Others mills used belt filter presses which also showed very high efficiency. Hence, in most cases a further dewatering of sludges can not be carried out or not justified, in principle, the investment. Lab trial however indicated that dewaterability of sludges, high in ash, are improved after the addition of those sludges high in fibre. In the case of this mixture would be selected for further applications, the investment in a mechanical dewatering system could be justified.

Drying is more critical than dewatering. Comparing direct and indirect dryers resulted that, in a long term, the most appropriate drying system is the multicoil, since it requires similar investment that rotary dryers but it is better controlled and more environmental friendly. Drying curves indicated that sludges differ in drying rate, although the same energy is required. Two first order rates were observed in the drying curves. The inflection point, from one rate to the other, occurs at the humidity where the sludge fluffy being different from one sludge to other.

After a detailed analysis of all drying and dewatering alternatives and a few tests carried out at the Kvæner Eureka facilities in Norway using different kinds of sludges, the main conclusion was that the indirect thermal drying technologies were the most suitable to dry sludges.

Conclusions of task 3: 1) Raw material generation and processing will not be limited by corrosivity (pH), abrasivity, toxicity and/or microbial degradation. 2) Screw press is the most appropriate sludge dewatering systems 3) Drying is the critical factor that determines sludge upgrading. 4) Multicoil is the most appropriate drying system. 5) Sludges differ in drying rates, and hence in drying time at a given condition.

4. Prototype to obtain raw material for trials

As we started to work on developing a prototype, it was made clear that two main problems should be solved: a) Product stickiness to the heating surface at certain moisture contents and b) Product transport inside the dryer (usually the more fibres we have in the sludge the more difficulties we find to make it "go through" the dryer). In order to solve these problems we designed a special variable speed recirculation system and we redesigned the original rotating heating surface of an existing dryer. The prototype was manufactured and installed near Tolosa.

5. Determination of Requirements for Different Applications

In principle, sludges can be used as a part or total component in kraft liners papers, test liners papers, corrugated boards, fluting papers and boards for cylinders, tubes and cover boards. Physical characteristics for these products were defined as well as the upper and lower limits that should be accomplished (Ochoa de Alda, 2007). The application of sludges in the wood sector was studied following the same method. In this case, the target product was the MDF (Medium Density Fibreboard). Methods for fibre mat forming and fibre mat pressing were defined as well as the methods for testing and quality assessment and industrial validation of the process.

Moreover, this task evaluated other alternatives for reuse and recycling of sludges. The study showed that the use of sludges in building material (lightweight aggregates, glass aggregate, and cement kiln) is well described and it is being currently developed in USA. Soil and agriculture utilization of sludges is also well described and its quality control and quality assurance procedures are being reported. However other applications are not so well defined. In the case of constructions material (hydraulic barriers and earthen structures) some development is required. Among other alternatives, the use of sludges as oil absorbent is a very promising alternative but technology and development must be improved (Crini, 2006; Chiang *et al.,* 2003).

Conclusion of task 5: 1) RTD performers posses the tools and knowledge to evaluate the feasibility of the use of sludges in the wood and paper sector. 2) These are the most upgraded alternatives for the reuse of high-in-fibre sludges (Type I).

6. Legal Advise (Health & safety regulations)

Mandatory regulations concerning production, management and application of sludges were reviewed. Only some management alternatives like the disposal in landfills, the incineration and land and agricultural applications are being currently regulated. Thus, an absence of legal regulations was observed in non conventional alternative managements. This does not appear to be a problem for the main objectives of the project (the reuse in the wood and paper sector) since the waste will be reused in industries having an efficient waste water treatment plant. Handling of sludges is not risky since most of its putative toxins have low volatility and exist in very low concentration. Although it is expected that toxin intake by skin exposure may exceed their intake by inhalation, dermal intake may be low at the concentration at which they are present (Cernec et al., 2005; Gillespie, 1999; Larsson *et al.,* 2002). However, there are legal barriers for the transport of wastes across the

European Union. This barrier can disappear if sludges are considered as a raw material and not as a waste.

The main conclusion of this review is that, although sludge appears to be non toxic for most applications, a proper quality assurance and control must be defined before a final demonstration trial.

7. Study of sludges utilization: Particular industrial applications

In the case of applications in the **wood industry**, the main objective was to study some products (like Medium Density Fibreboards, MDF) manufactured using solely sludges as raw material. Therefore it was firstly required a) to find the appropriate working process to manufacture MDF at a laboratory scale, optimizing the values of the process's parameters, b) to test different types of sludges as MDF raw material. Results were compared with commercial industrial fibre (Table 1).

Sample	Adhesive	% Moisture	Specific gravity (kg/m^3)	Bending strength (kg/m^2)	Modulus of elasticity (kg/m^2)	Machinability
Type I	UME	5.3	840	155	12000	4,5
	UFM	5.9	750	80	6000	3
Type II	UME	4.9	960	65	4000	—
	UFM	4.7	1000	45	3000	3
Type IV	UME	1.4	1350	10	2500	—
Wood	UFM	5.41	860	65	5500	—
Standars		**5-9**	**700-800**	**250-320**	**21000-25000**	

Table 1. Properties of fibre boards manufactured with sludges (types I, II and IV) compared to the performance of industrial wood fibre. Urea-formaldehyde (UFM) and urea-melamine (UME) were used. Standars for MDF are included in the table.

The best results were achieved using Type I sludges which performed even better than the industrial wood fibre. Hence, sludges type I are suitable to be used as raw material in MDF. Sludges Type II can be used as a raw material for MDF and as a filling substance in other wood panels. In contrast, sludges Type IV are not suitable for fibreboard production. This sludge, however, could be used as a filling substance in other wood panels and even fibrecement panels. All the results performed in the laboratory are expected to be surpassed by the results obtained in an industrial process.

In the case of applications in the **paper industry** the main objective was to estimate at laboratory and pilot plant scale the feasibility of reuse sludges in the paper and cartonboard sector. For this purpose it was analyzed the physical, surface and optical properties of handsheets containing sludge (Ochoa de Alda, 2007). It was observed that he reuse of high fibre content sludges, type I and II, produced in paper applications are conditioned for the process that they are coming from. For instance, the strength, surface and optical properties of handsheets made with sludges originated in a bleached kraft process, where most of the rejects are white (thus, they are rejects of the thickening stage after bleaching), are as good as pulp. This sludge could be used in printing and writing grade papers and newsprint papers. The quantity of sludge would depend in the characteristics of the end product and machine runnability. Their acceptance in papers made of secondary fibres (recycled) would be easier. In contrast, sludges from a kraft process of *Pinus insignis* (where the rejects are unpulped wood, lime grit rejects and fibres with high strength properties and dirty aspect) could be used in cartonboard applications for testliners.

The application of high-fibre sludge in upgrading papers (high quality papers or premier) without contaminant removal is not possible due to the appearance factor. Most of the sludges analyzed showed a bad appearance which could make the quality of the papers to decrease in the end product. These sludges should be used in papers where appearance is of secondary importance, this is in chipboards, OCC based corrugated board, folding papers. The inside of a corrugated case of multy - ply board or a multy - ply board are not printed and is seldom seem, so that its appearance and surface are not so important as those of outside liner. Sludges without cleaning/screening process could be used successfully in board.

Conclusions of task 7: 1) Most of the sludges high in fibre may be used in multilayer board, or in some cases even in high - quality paper. 2) sludge´s fibre mainly originated from a sulphate pulp process are highly potential raw material. 3) Some of the sludges high in ash, can be cleaned and used in paper and boardmaking as a filler source. This type of sludges does not contribute in the fibre bonding.

8. Study and testing of applicability at industrial level

Reuse and recycling of sludges were studied and tested at a precompetitive level. The main goal was to obtain feedback from the application of sludge-based raw material in real industrial processes. Samples of sludges were sent to potential customers a) two manufacturers of composites, b) nine manufactures of wood panels and c) eight writing paper mills and cartonboard mills.

Manufacturers of composites (composites of fibre plus gypsum or cement) were interested in use sludges together with its common raw material. The manufacturer of cementitious composites were very interested in reuse sludges because they are currently employing asbesto and are trying to replace this artificial fibre by cellulosic fibres. However they found that a) *Eucalyptus* fibre of sludge is to short to be used in its current process b) sludges having longer fibres (*Pinus*) contained organic material –out of the fibre- that interferes in crystallization of cement, c) process could be optimized to use sludges as a part of raw material but it must be first demonstrated that short-term results of test composites are maintained in a long-term since, unsatisfactory experience with other cellulosic fillers requires long-term durability and dimensional stability testing of the material. The manufacturer of fibre-gypsum composites are interested in replace fibre-glass by the fibre of sludges, however they can not include sludges in its current process since it should be first incinerated.

Manufacturers of wood panels were interested in the final product. However, only two mills tried homogenization of resins and fibres. In one case, homogenization was unsatisfactory since dry sludge get lumpy and after pressing result in a weak board. In the other case, MDF mill respond that sludge's dust generate resin condensates that affect appearance of the final product. They provided us its common raw material, allowing to compare in the laboratory the physical performance of a common raw material and sludges. Results carried out in the laboratory indicated that sludges can replace or mixed with the current raw material.

The objectives marked in this task 8 in the paper sector were: a) to demonstrate at industrial level results obtained previously in laboratory tests. b) To accumulate knowledge about problems that must be solved prior to an industrial utilization of the sludge in the paper industry. Two main problems could be found in the introduction of sludges as fibre content raw material into virgin fibre or secondary fibre furnishes: 1) the build up of suspended solids among other factors could affect machine runnability and can cause deposits. 2) Sheet properties, appearance, and performance could be affected.

Depending on the efficiency of the cleaning and screening systems, the presence of sludges fibres could increase the dirt count and the number of holes in the sheet. Sludge´s fibre sheets could also tend to be weaker than virgin - fibre paper (Ochoa de Alda, 2007).

An industrial trial was made with sludges in a waste based papermaking process. In this trial as it was expected some problems on machine runability occurred due to poor drainability. This was solved by adjusting a drainage agent in the process. Sheets tend to be weaker while the optical properties increased with the type of sludge added.

Conclusions of task 8 were that further trials at industrial level are required to see the effect of sludges on the water system, wire and press part and in the dryers to adequate sludges to a papermaking process. It is also important to know sludges properties for particular productions.

9. Economic analysis and detailed exploitation plan

The viability study prioritized the interest on real figures and targeted actions for the first years of exploitation, in detriment of a more ambitious and enthusiastic plan. In this sense, all the collection of sludge (starting point in the economical chain of the business) targets specific paper mills rather than percentages of the whole volume of sludges available in the geographical area of interest for the partners.

A complicated aspect of the analysis has derived from the important fluctuations of market prices of chemical pulp. These prices either limit or open the real possibilities to recycle sludge. This aspect was taken into account by presenting different market scenarios that concluded with some criteria about how to act depending on fluctuations of market prices of chemical pulp.

The objective at this stage of the project has not been to specify business potential at a partner level. Considering all the different aspects signed up in the "Consortium Agreement", the sharing of results and markets will be defined in the exploitation plan.

Conclusions of task 9: 1) Recycling in the paper sector can be highly encouraged after analyzing low investments needed, low technical risk at this stage of the project; and, contacts made along the project. It is recommended with market prices for the chemical pulp higher than 375 €/ton.) Recycling in the wood panel sector is not economically feasible if we consider the cost of different dewatering-drying methods. The interest may come in the following cases: a) when the wood panel manufacturer has wet gluing technology; b) the dewatering-drying systems are optimized; or c) it is considered interesting to have business alternatives to the paper sector to assure sludge collection and recycling in periods of low prices of this sector. 3) It is also encouraged to deep into the technical possibilities of applying the sludge as barriers in land-fill applications. Lack of these materials and their prices are a good argument for it.

Conclusions

Primary sludges from chemical pulp mills can be used in paper and board products were the appearance is not critical.

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