IMPACT OF INCREASED COLLECTION RATES AND THE USE OF COMMINGLED COLLECTION SYSTEMS ON THE QUALITY OF RECOVERED PAPER. PART 1: INCREASED COLLECTION RATES

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ABSTRACT

The recovery and utilization of recovered paper have increased over past decades all over the world due to economic, environmental, and social issues. However, it is well known that an extended recovered paper collection is detrimental to its quality, either by the exploitation of lower quality sources such as households, or the spreading of commingled systems instead of selective collection systems. The influence of these two factors was assessed by analyzing the quality of different recovered paper grades used as raw material in a mill located in Madrid (Spain) producing newsprint and light weight coated paper from recovered paper. Part 1 of the paper deals with the impact of increased collection rates on the quality of recovered paper and Part 2 with the use of commingled collection systems. Results of Part 1 show that increased collection rates have a large impact on the quality of the recovered paper. The quality, measured as total unusable material and moisture contents, had deteriorated very rapidly in only four years (2005-2008) as a consequence of increased collection rates. Collection rates increased in Spain from 58.5% to 68.6% during this period, resulting in more than 50% increase of total unusable material and 25% of moisture content. The downgrading of the quality of recovered paper is one of the major threats for extending the current limits of paper recycling. Therefore, future challenge is to increase its availability but maintaining its quality.

Keywords: recovered paper; paper recycling; collection rate; collection systems; quality

1. INTRODUCTION

The recovery and utilization of recovered paper has increased over the past decades all over the world, and this trend will continue, due to economic, environmental and social reasons. Paper recycling has traditionally occurred because it has been economical compared to the use of virgin fiber, especially in some paper grades such as newsprint or packaging. In addition, paper recycling has also a number of environmental benefits. Apart from reducing the use of wood as raw material and avoiding used paper to be landfilled, paper manufacturing based on recovered paper consumes less water and energy per ton of product (Schmidt et al., 2007; Villanueva and Wenzel, 2007). Furthermore, social issues impact on paper recovery and utilization. Environmental awareness by people puts pressure on recycling even more, it also influences legislation and regulations, and the strategy of companies when consumers buy environmental-friendly products (De Feo and De Gisi, 2010; Miranda and Blanco, 2010b).

In Europe, after the success of the first European Declaration on Paper Recycling (2000-2005), a new voluntary commitment on paper recycling chain was signed with the aim of achieving a recycling rate of 66% in 2010 (ERPC, 2006). This objective was already

achieved in 2008 (66.7% recycling rate), and even a 72.2% recycling rate was achieved in 2009, despite the world economic crisis. This achievement strengthened the position of Europe as the global leader in paper recycling (ERPC, 2010).

To extend the current limits of paper recycling, one of the key factors is to improve the availability of recovered paper. However, it is well known that an extended recovered paper collection is always detrimental to its quality (Faul, 2005; Levlin et al., 2010). The reason is that first are exploited those sources of recovered paper with the highest quality and are easier to collect (high volumes of recovered paper generated at individual points), while if the collection rate increases, other sources with a lower quality and more disperse generation are exploited, as the recovered paper coming from households (Neukum et al., 2001). This effect is especially important if the collection rates are already high, when the industrial sources are already tapped (high quality sources) and there is a need to increase the recovery rates of recovered paper from households (low quality sources).

On the other hand, commingled collection systems have been usually argued as a method for increasing the recovery rates and, consequently, the availability of recovered paper, thus reducing the collection costs at the same time (Emerson, 2004; WRAP, 2004; Faul, 2005; Clapp, 2006; Kinsella and Gertman, 2008). However, the shift from source-separated collection systems to commingled systems has been considered as one of the major threats to the recovered paper quality and one of the most significant changes in the recycling industry in recent years (Miranda et al., 2010a; Sacia and Simmons, 2006). Commingled collection systems are gaining more and more importance in some countries, especially in the United States and United Kingdom, but they are also spreading to other European countries such as France (Faul, 2005). In these collection systems, all recyclable materials are collected together in a single container, and include a mix of paper and board, glass bottles, cans, plastics, etc. Although the materials are then sorted in a materials recovery facility (MRF), the recovered paper is highly contaminated, e.g. total unusable materials can vary between 5 and 20%. Part 2 of the article is focused on the impact of using commingled instead of selective collection systems on the quality of recovered paper.

Besides, the cost pressure for segments of the recovered paper supply chain often counteracts against possible and necessary quality improvements of the recovered paper (Wagner et al., 2007). Furthermore, the use of deinked pulp has also become common in grades which were traditionally produced from virgin fibers, e.g. graphic papers, where the quality requirements for the final product are higher (Faul, 2005) and the quality demands for the finished paper are also increasing with the rapid technological development of the publishing and converting industries (Miranda et al., 2010a). All these factors limit the possibilities of the mills to accept recovered paper deliveries of insufficient quality. Although an effective quality control at the mill can help control the quality, this approach is not truly possible due to the characteristics of the recovered paper supplied, economical considerations and the degree of availability of raw materials.

The quality of recovered paper depends on several factors but unusable materials content is one of the determining factors (Levlin et al., 2010; Spiess and Renner, 2004; Faul, 2010). According to the European List of Standard Grades of Recovered Paper and Board (EN 643), material unusable in the production of paper and board consists of

non-paper components and paper and board detrimental to production. In the United States, the nomenclature is slightly different: “prohibitives” are used instead of “non-paper components”, “outthrows” or “unwanted materials” instead “paper and board detrimental to production” and “total unwanted materials” as “unusable materials”. Non-paper components consist of any foreign matter which during processing, may cause damage to machines or interruptions to production or may reduce the value of the finished product. Such foreign matter might include metal, plastic, glass, textiles, wood, sand and building materials, synthetic papers, garbage, rubber bands, personal adsorbents, etc. Paper and board detrimental to production are grades of paper and board which have been recovered or treated in such a way that they are, for a basic or standard level of equipment, unsuitable as raw material for the manufacture, or are actually damaging, or whose presence makes the whole consignment of paper unusable. In the case of graphic papers such as newsprint, light weight coated or supercalendered papers, all old newspapers (ONP) and old magazines (OMG) belong to the desired papers and all brown and gray packaging is classified as unsuited. But there are also household waste papers for which the rating is not as clear and every paper mill has to set its own specifications depending on the recovered paper grades purchased and the type of recycled paper grade which is produced (Faul, 2005). The following papers and boards are usually considered as detrimental to production for graphic papers: old corrugated containers (OCC), kraft bags, folding carton, telephone books, carbonless paper, colored paper, catalogs, stickies, carbon paper, junk mail, wax paper, etc.

According to EN 643, recovered paper should in principle be supplied free of unusable materials, but for specific grades, a certain proportion of unusable materials can be agreed between purchaser and supplier, although it shall refer solely to the element described as “paper and board detrimental to production”. In the case of grade 1.11 (sorted graphic paper for deinking), EN 643 states that the percentage of paper and board detrimental to production should be reduced over time to a maximum level of 1.5%, although at the time of writing this level is negotiated between buyer and seller. The same percentage has been proposed as “end-of-waste” quality criteria for recovered paper (Villanueva and Eder, 2011), according to the “end-of-waste” mechanism introduced by the new Waste Framework Directive (2008/98/CE) of the European Union. The purpose of this mechanism is to encourage recycling by creating legal certainty, an equal level playing field and removing unnecessary administrative burdens. Thus used paper ceases to be a waste and become a secondary material.

Paper and board detrimental to production, but mainly boards, are usually rejected by the pulper, these losses result in low process yield and also imply additional waste management costs. In addition, these materials reduce the optical properties of the pulp, cause an increased content of stickies and their associated costs, and increase the contamination load of waters (Neukum et al., 2001; Patrick, 2006; Roring et al., 2006; Miranda et al., 2008b; Miranda and Blanco, 2010c). Problems associated with non-paper components are even more important than those caused by paper and board detrimental to production. They are mainly plastics and aluminum cans, although glass, textiles, building materials, etc. can be present, but in a lower concentration. These materials are mainly removed as rejects in the pulper, making it necessary to replace them with additional recovered fiber, besides increasing the costs of management of the waste, etc. A larger effect is caused by plastics, due to its high volume compared to aluminum cans. There are also specific problems for some of these materials, i.e. glass is critical, especially from commingled collection systems. Glass affects operating costs

of process by increasing the wear and tear rate of process equipment, maintenance, downtime, and safetime risks. If levels of incoming glass exceed 0.5% even the process could be shut down (Sacia and Simmons, 2006).

Another important quality parameter of recovered paper is the moisture content. According to EN 643, this is limited to the naturally occurring level. When the moisture content is higher than 10% (of air dried weight), the additional weight in excess of 10% may be compensated for with the method of testing and sampling to be agreed between buyer and seller. The high moisture content implies an important additional cost to replace the lower share of fibers and it is the most determining factor in the biodeterioration of recovered paper during storage, especially if the temperature of the environment is suitable for bacterial growth, causing foul odors, loss of brightness, etc. (Blanco, 2003).

The already high collection rates of recovered paper are one of the major threats to its quality. The increase of availability of recovered paper needs to be addressed together with the quality of recovered paper (Levlin et al., 2010; Miranda et al., 2010a). Quality is a major prerequisite for extending the use of recovered paper as raw material, the major threat being insufficient quality offered (Miranda et al., 2010a). In this sense, a considerable amount of research and initiatives to improve the furnish quality are going on at present around the world.

The objective of Part 1 of this paper is to describe the effects of higher collection rates on the quality of recovered paper by analyzing the quality of the recovered paper collected from households by selective collection methods and used by a Spanish mill producing newsprint and light weight coated paper.

2. METHODOLOGY

To determine the impact of increased collection rates on the downgrading of the recovered paper, the quality of the most important source of recovered paper used as raw material by a Spanish mill was monitored during a four year period, from January 2005 to December 2008.

Quality of the recovered paper was assessed by total unusable material and moisture contents. Unusable material content measurements have been focused in the mixture of ONP and OMG collected separately from households. This is the most important recovered paper grade used by the mill as raw material and this is the source with a higher content of unusable materials (compared to other primary raw materials such as unsold newspapers or magazines, with almost negligible unusable material contents). On the other hand, moisture content was monitored in all the sources of recovered paper used by the mill.

2.1. THE SPANISH CASE: INCREASED COLLECTION RATES

The Spanish case was selected for a number of reasons. First, Spain is a global leader in the use of recovered paper as raw material by the paper and board industry. In 2009, nearly 81% of the paper and board produced in Spain used recovered paper as raw material, versus an average of 50.7% in European countries (EU27 + Norway + Switzerland) (CEPI, 2010).

Second, there is a deficit of recovered paper balanced by imports from closer European countries (mainly France and Portugal). Net trade of recovered paper is around 0.50-0.75 million metric tons, depending on the year, which represents approximately 10-15% of the recovered paper utilized (Miranda and Blanco, 2008a).

Third, paper recovery in Spain was not so developed as in other European countries such as Germany, Austria, or the Netherlands, who are world-wide leaders both in collection and utilization of recovered paper as raw material. To improve this situation, a lot of effort has been spent during recent years by implementing and improving the collection systems and increasing environment awareness of the people (Miranda and Blanco, 2008a). These efforts have yielded very rapid increases in the collection of recovered paper. In fact, in the last decade, the collection has been almost doubled: from 2.63 million metric tons in 1998 to more than 4.98 million metric tons in 2008 (Figure 1), with an average annual increase of 7%. At the same time, the collection rate has increased from 43.4% in 1998 up to 68.6% in 2008 and now Spain is at an European level (in 2008, the average collection rate in Europe was 67%). Collection rate is defined as the volume of collected paper expressed as percentage on the total consumption of paper and board. It is usually used instead of the term paper collected because this takes into account the paper consumption, which sets the limit on the paper which can be collected and, consequently, reflects more accurately the collection efforts.

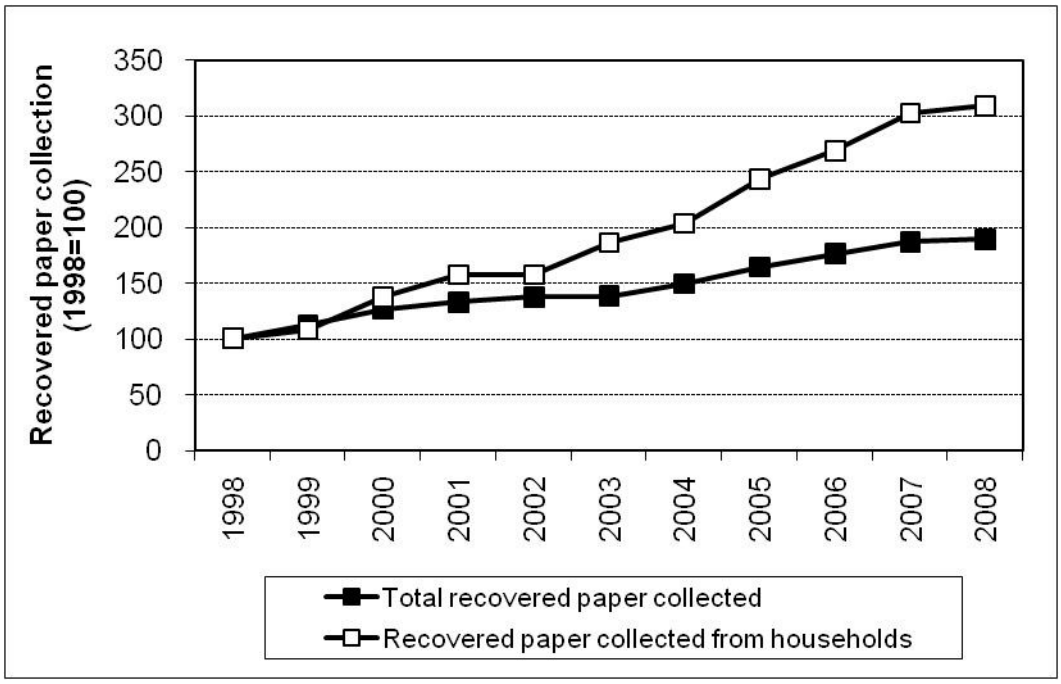

Figure 1.- Collection of recovered paper and collection rate in Spain during the period 1998-2008.

Consequently, the impact of increased collection rates can be followed by the analysis of the quality of the recovered paper collected during recent years in Spain. In the period studied, from 2005 to 2008, the volume of recovered paper collected increased from 4.32 to 4.98 million metric tons (15%) and the collection rate increased 10 points, from 58.5% to 68.6%. This increase occurred mainly due to the increase of recovered paper collected from households, the most important source of recovered paper with still low recovery rates (Miranda and Blanco, 2008a). Overall, between 1998 and 2008

the collection of recovered paper from households almost tripled, from 0.348 million metric tons to 1.076 million metric tons, increasing the share of recovered paper from households of total recovered paper collected, from approximately 13% to 22%. During the 2005-2008 period, the recovered paper collected by the municipal channel increased from 0.831 million metric tons to 1.076 million metric tons, which means almost a 30% increase in only four years, even after taking into consideration that paper consumption decreased in 2008. This means selective collection from households had increased 2-fold than total collection of recovered paper in four year period.

2.2. SOURCES OF RECOVERED PAPER

To study the influence of increased collection rates on the quality of the recovered paper, the main source of recovered paper for the largest mill newsprint and light weight coated paper mill in Spain, was analyzed for the period 2005-2008. The mill is located at Madrid (Spain) and produces 475,000 metric tons/year of newsprint and light weight coated paper based on 100% recovered paper.

This mill was selected first because graphic paper production is the most obvious in terms of the quality of recovered paper, and second, because it uses as raw materials old newspapers (ONP) and old magazines (OMG). This raw material is mainly obtained from households, which is the source with the highest collection increase in Spain in recent years.

Different recovered paper grades are used as raw material by this mill. The share of each recovered paper grade varies with time, according to the availability of the raw material, and the final product considered. In general, it can be said that around 50-60% of the recovered paper used as raw material is a sorted mixture of ONP and OMG from the selective collection of recovered paper from households. In addition, the mill uses unsold newspapers and unsold magazines, both used at approximately the same proportion, representing together 30-35% of the raw material. The rest, 5-20%, are different grades from other sources, including some high quality grades such as white shavings from printing and converting operations and low quality grades such as the recovered paper coming from commingled collection systems, imported from United Kingdom.

The present study focuses on the main recovered paper grade used by the mill: a sorted mixture of ONP and OMG sourced from the selective collection of recovered paper from households.

2.3. UNUSABLE MATERIAL CONTENT MEASUREMENTS

Unusable material was measured using gravimetric analysis from a recovered paper sample of approximately 40 kg before and after the isolation of all the unusable material present according to the general rules of EN 643. Regarding the specific materials considered as unusable at the studied mill, it is necessary to consider that all the board is assumed to be detrimental to production together with carbon paper, wet-strength papers, colored papers, paper with glue or polycoated or with waxes and paper treated with non-water soluble adhesives.

The determination of the total unusable material content was planned to be performed on a regular basis of approximately 3 times per day (once on each shift) during the 4-year period (2005-2008). However, due to different logistic problems during the study, a total of 2,751 samples were analyzed, which corresponds to around 2 samples per day. Daily averages were used instead of raw data for statistical calculus due to the high variability of the values, even for the same day. Consequently, a total of 1,083 daily averages were used in the calculations: 257 in 2005, 302 in 2006, 277 in 2007 and 247 in 2008. These values covered almost 75% of the days during 2005-2008, with an average of more than 2.5 samples per day (2751 samples sampled during 1083 days). Table 1 shows the number of samples analyzed together with the number of daily averages by month during the analyzed period.

Table 1.- Samples analyzed for unusable material content during the study. Available daily averages are between brackets.

	2005	**2006**	**2007**	**2008**
January	36 (19)	74 (25)	70 (24)	31 (18)
February	38 (20)	70 (25)	70 (28)	57 (21)
March	41 (21)	81 (27)	67 (31)	39 (20)
April	50 (22)	65 (21)	63 (26)	56 (22)
May	37 (19)	82 (26)	58 (26)	35 (18)
June	44 (22)	78 (26)	64 (24)	52 (22)
July	46 (20)	78 (27)	53 (21)	52 (22)
August	38 (21)	66 (24)	49 (22)	67 (20)
September	44 (20)	49 (22)	40 (22)	68 (22)
October	65 (24)	74 (26)	43 (22)	66 (23)
November	72 (25)	74 (27)	51 (18)	55 (19)
December	72 (24)	72 (26)	42 (13)	57 (20)
Total	583 (257)	863 (302)	670 (277)	635 (247)

2.4. MOISTURE CONTENT MEASUREMENTS

Moisture was measured after oven-drying the sample of recovered paper at 105ºC, according to ISO 287:1985 “Determination of moisture content – oven-drying method”. The analysis was carried out on a regular basis during the studied period, with around 8 samples per day. Moisture was measured not only in recovered paper from households selective collection but also in other recovered paper grades used as raw material by the mill. Monthly averages from 2005 to 2008 were considered as the raw data for the statistical analysis of the present study.

3. RESULTS AND DISCUSSION

3.1. IMPACT OF INCREASED COLLECTION RATES ON UNUSABLE MATERIAL CONTENT

Unusable material content of the paper from selective collection rapidly increased during the period 2005-2008, from 5.5% to 8.7%, which means an average increase of 57% (Figure 2). This means a remarkable deterioration of the recovered paper collected from households in only four years due to the rapid increase in the collection rates of

recovered paper, from 58.5% to 68.6%, and especially recovered paper from households, which increased approximately 30% in the same period (almost two-fold than total recovered paper collection). In addition, the deterioration of the quality of recovered paper is faster each year: the variation of unusable material content was 0.80% between 2005 and 2006 but increased to 1.06% between 2006 and 2007, and 1.30% between 2007 and 2008.

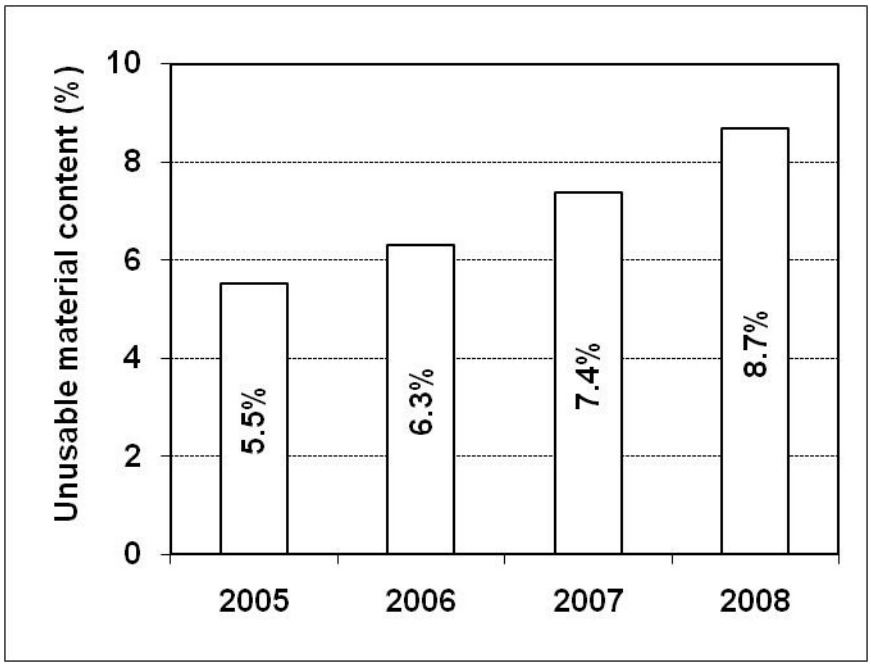

Figure 2.- Unusable material content of recovered paper from households' selective collection. Annual averages from 2005 to 2008.

If we analyze the minimum and maximum daily unusable material content measured in each month ("monthly best" and "monthly worst" values, respectively), a continuous increase of both values can be observed for the period, especially in 2008. The average "monthly worst" in 2005 and 2006 was lower than 8.0% while this average increased up to 10.9% in 2007 and 13.7% in 2008. In addition, during 2008, samples with unusable materials content higher than 10% appears in some samples each month. In the case of the "monthly best" an increase during the analyzed period was also observed, but to a lesser extent that "monthly worst" values. The average of "monthly best" values increased from 3.8% in 2005 to 5.0% in 2006, 5.5% in 2007 and 5.1% in 2008.

As can be seen in Figure 3, showing the monthly average of unusable material content during 2005-2008, summer was the period in which the unusable material content of the selective collection entering to the mill was the highest. In summer, average unusable material during 2005-2008 was around 8.0% while the unusable material content during winter, for example, was around 6.0% on average. This is a specific seasonal effect for this mill which can be explained through its special characteristics of location, in the centre of Spain. During summer time, there is a real scarcity of recovered paper due to holiday period. The collection of recovered paper around Madrid decreases very much and lower quality recovered paper is bought. In fact, some qualities and grades are used only in summer by the mill and not during the rest of the year. These seasonal effects are common, Fairbank et al. (2006), for example, described other seasonal effect which occurred during January of each year in Canada. In this case, it was observed that a

large increase in paper and board detrimental to production (especially boxboard and old corrugated containers), collected together with ONP, was due to Christmas presents.

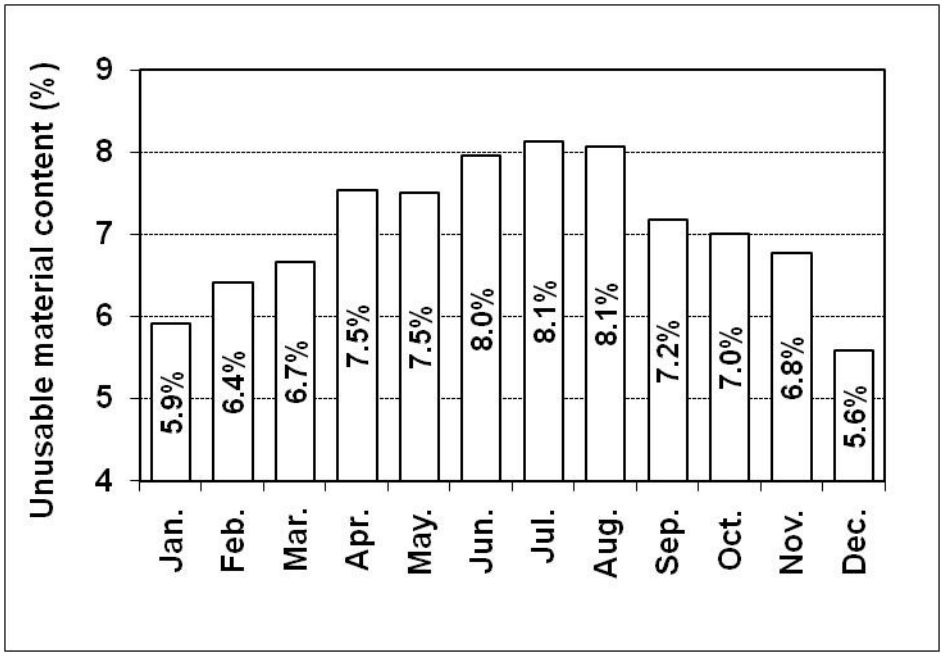

Figure 3.- Monthly unusable material content variation during the period 2005-2008.

Another example of the downgrading of the quality of recovered paper during the analyzed period is shown by comparing the cumulative frequency distribution of samples for the same month in different years, in order to avoid the previously mentioned seasonal differences. Figure 4A shows these frequency distribution curves for the month of May. The number of available daily averages was: 19 in 2005 (based on 37 analyzed samples), 26 in 2006 (82 samples), 26 in 2007 (58 samples) and 18 in 2008 (35 samples). This means the number of samples used for the calculation of daily averages varied between two and three.

In May 2005, a 50% of the daily samples collected had a content of unusable material higher than a 5.5% content but in 2006 and 2007, this value had increased to approximately 6.0% and 6.5%, respectively. However, the major increase occurred in 2008, when 50% of the samples measured had an unusable material content that was higher than 11%. This was because of an unusual situation at the sorting plant supplying the recovered paper. Figure 4B shows the distribution of samples among different unusable material contents. In the case of May 2005, 2006 and 2007, the major percentage of the samples (between 65% and 75%, depending on the case) has an unusable material content between 5% and 7.5%. In May 2008, however, the major number of samples (a 66% of the samples) had an unusable material content higher than 10%. The deterioration of the quality of the recovered paper from households can be observed very clearly in the range 2.5-5%; the percentage of samples with unusable material content in this interval is lower every year. The same conclusion can be reached by analyzing the proportion of samples with unusable material content between 7.5% and 10%, or with unusable materials higher than 7.5%. The proportion of samples with unusable material content between 7.5% and 10% increased from 3% in May 2005, to 16% in May 2006, 23% in 2007 and 31% in 2008.

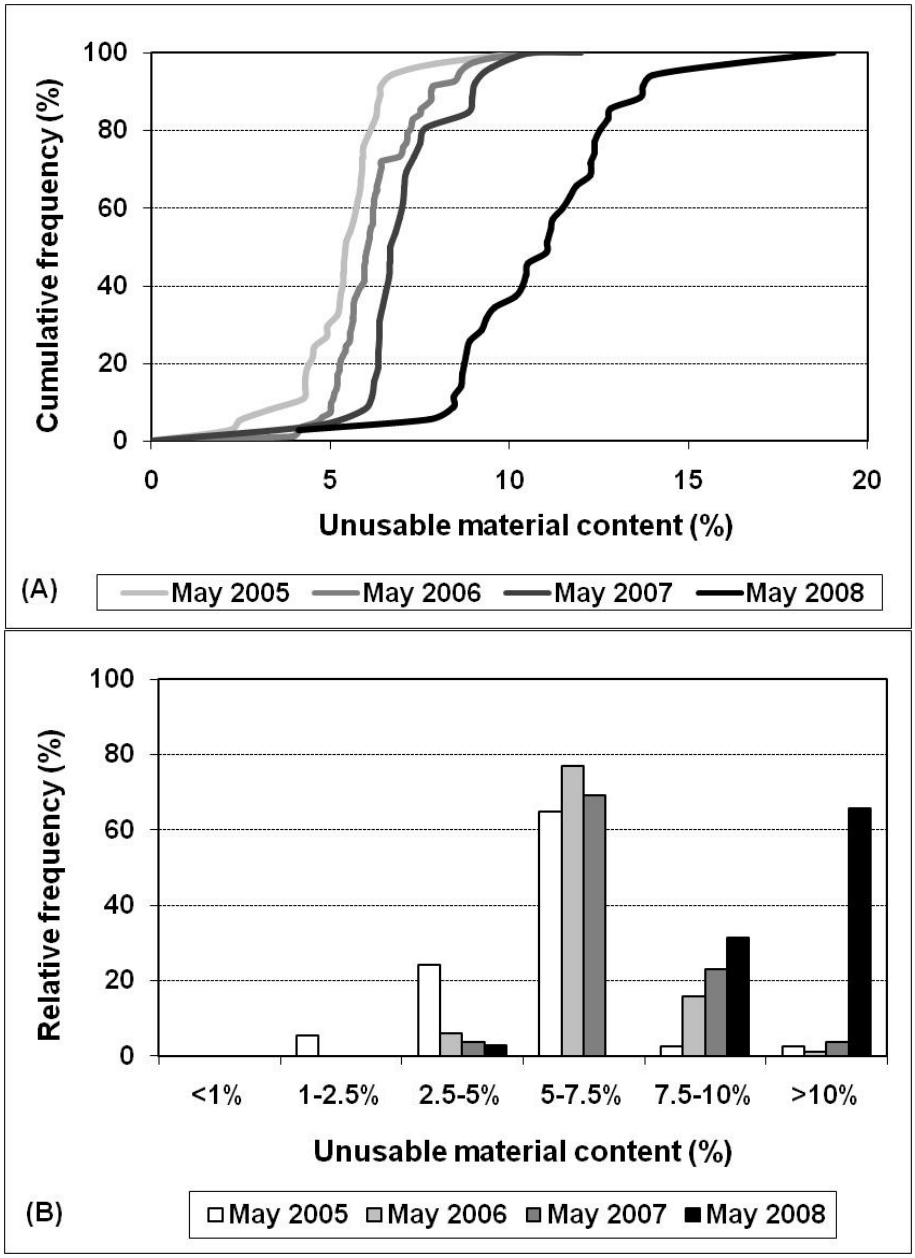

Figure 4.- Total unusable material content during May of 2005, 2006, 2007 and 2008: (A) Frequency distribution curve of the daily averages, and (B) Relative frequencies by ranges.

Next, the discussion of the obtained results is presented. Firstly, the values obtained for unusable material content will be compared with the values obtained in other surveys, with the established limits of contamination in EN 643, and the proposed "end-of-waste" quality criteria. Secondly, the variation of the unusable material content during the analyzed period will be compared with the results obtained by other studies analyzing the degree of contamination with time and/or collection rates. Thirdly, rough estimations of the additional costs to compensate for the downgrading of the recovered paper will be presented.

Comparison of the results of unusable material contents with the results obtained in other surveys and the proposed quality limits. In a study carried out during the year 2007 by the National Associations of Recovered Paper Dealers (REPACAR) and

Manufacturers of Pulp and Paper (ASPAPEL), the average degree of contamination of recovered paper in Spain was determined in terms of moisture and unusable materials (ASPAPEL and REPACAR, 2008). For grade 1.11, sorted deinked selective collection, which is the main recovered paper grade for deinking production, an average of 7.28% of total unusable materials were obtained, with 6.14% paper and board detrimental to production (a 84.3% of total unusable materials) and 1.14% as non-paper components (a 15.7% of total unusable materials). The material with the highest presence in unusable materials were corrugated board and cartonboard, with an average content of 3.17% and 2.52%, respectively, representing together more than 90% of paper and board detrimental to production and around 80% of total unusable materials. These values are in agreement with the average value of 7.4% for unusable materials in the recovered paper from household selective collection used by the mill during 2007.

The results are also in agreement with Bösner et al. (2008). They made an analysis of 38 deliveries from 10 mills (8 from Germany and another 2 from Austria) of grade 1.11 and they obtained a 6.7% total unusable material content on average, 6.3% paper and board detrimental to production and 0.4% non-paper components. Brown and grey board represented 60% of paper and board detrimental to production (57% of total unusable materials) and white board 14% of paper and board detrimental to production (13% of total unusable materials). The rest 1.3% was unsuitable paper and 0.3% other boards.

As mentioned before in the Introduction, EN 643 specifies a long-term target of 1.5% maximum content for grade 1.11, but the actual percentage at the time of writing is negotiated between buyer and seller. In case of high unusable material contents (e.g. > 3%) customers most often refuse delivery of the recovered paper consignment (Wagner et al., 2006). In a survey carried out among the members of the International Association for Deinking (INGEDE), that analyzed paper and board detrimental to production, the non-paper components, and the total unusable materials between 1999 and 2005, the average content of total unusable materials among participating mills was around 2% (Faul, 2005). Most of the mills surveyed had a limit for the total content of unusable material, disregarding whether it comes from non-paper components or paper and board detrimental to production. These limits range from 1% to 6%, but in most cases, between 3% and 5%.

In the paper mill under study, the total unusable material content was very high compared to the EN 643 and the proposed “end-of-waste” criterion but also with the regular qualities used among INGEDE members. This is due to the fact that the mill needs to accept low quality recovered paper due to the lack of availability of raw materials in Spain. In fact, since the end of 2007, the mill started to use a new grade of recovered paper from households with a very high unusable material content (between 3% and 15%). Before this, recovered paper with unusable material content higher than 3% was always sorted again to achieve the required quality. However, an increased sorting effort could lead to lower production of sorted recovered paper (not only unusable materials are rejected but also valuable deinking materials) and, in the most extreme cases, recovered paper could be sent to board mills instead of deinking mills, thus, reducing the available deinking grades for newsprint and light weight coated paper production. In addition, a more recent survey among INGEDE members has demonstrated that the quality of recovered paper is very different across Europe: while

in Central Europe the average unusable material content is around 2%, the average unusable material content in South Europe is around 4-5% (Faul, 2009; Faul, 2010).

Comparison of the variation of the quality of the recovered paper with time and/or collection rates with previous studies. In the surveys among INGEDE members, it was found that the percentage of unusable papers has not changed significantly over the years. This was considered as a small success against a background of increased collection rates in Europe (Faul, 2005). The same was observed in terms of non-paper components by Neukum et al. (2001). The quality of the EN 643 recovered paper grades 1.01, 1.02, 1.04, 1.11, 2.01, 2.05 and 4.03 was investigated systematically using more than 30 parameters and sampling was performed quarterly in five different German states over a time period of two and a half years. In this case, the results indicated no general deterioration in the cleanliness (as a proportion to non-paper components) of the recovered paper grades.

However, most of the mills which are members of INGEDE are from Germany, and the situation in Germany is very different from the situation in Spain. For example, from 1998 to 2008, apparent collection of recovered paper in Germany increased from around 11.9 million metric tons to 15.6 million metric tons (around a 30% increase) and the collection rate increased from 69.9% to 74.1% (only 4.2 points). The situation is completely different to Spain, where the collection rate increased more than 25 points from 1998 (43.4%) to 2008 (68.6%), and 10 points even in the 4-year period analyzed in this study (2005-2008). This explains why the studies by INGEDE have not demonstrated an important deterioration in the quality of recovered paper. In addition, the more recent INGEDE study also demonstrated that in Central Europe there has not been any significant variation in the six years between 2002-2008, an average of 2% of total unusable material content. However, in South Europe, the total unusable material content is not only higher but increasing with the time, e.g. increased from 3% in 2002 and 2003 to 4-5% during 2004-2008 (Faul, 2009; Faul, 2010).

Fairbank et al. (2006) also compared the collection rate in Canada with the level of dirt in a mill producing newsprint from 100% DIP during 10 years, from 1991 to 2001.They observed that the level of dirt rose as the total recovery rate increased over the years and due to the competition for recovered paper. In this case, the collection rate increased around 10 points in the period 1991-2001, from 31.7% in 1991 to 42.3% in 2000 and 40.0% in 2001. This means a similar increase in the collection rate that occurred in Spain in the 4-year period considered in this study.

Estimation of the additional costs related to a higher content of unusable material. In a simplified approach, these costs are related to three factors (Strunz, 2005): a) the prices of recovered paper (there are fewer fibers per ton of recovered paper), b) the costs of waste disposal (landfill taxes) and c) the solids content of the waste to be disposed (which implies more tons to be landfilled). Unusable material content increased around 3.2 points in the 2005-2008 period, from 5.5% to 8.7%. If we consider that around 50% of the raw material used by the mill is from this source, a global 1.6% increase in the unusable material content of the furnish has occurred. This would imply a 1.6% additional consumption of recovered paper. For a typical newsprint mill producing 300,000 metric tons, the additional costs assuming an 82% yield in the process and €100/ton as the price (deinking grade 1.11), would be as high as €600,000 per year.

In addition, it is necessary to consider the disposal cost of waste. These costs depend on the costs of waste disposal (landfill taxes) and the solids content of the waste. The solid content of the waste is different depending on the stage where the waste is rejected. If unusable materials are rejected from the process in the pulper, the water content of the waste is low and consequently, the waste disposal costs. However, if unusable materials are rejected as other wastes such as deinking sludge, water treatment sludge, etc., the water content can be as high as 40-80% (Monte et al., 2009). Although non-paper components are usually rejected in the pulper, paper and board detrimental are not always rejected in the pulper. Some fibrous materials can be present at the final product although this implies some drawbacks: brightness loss, increased stickies content, etc. This lower quality final product could be compensated for by more rejects leaving the system or chemical treatment implying lower yields or higher costs in the process. Even in the most favorable case, in which only non-paper components are rejected from the process and are pulper rejects (where the water content is low), the mill would face important additional costs.

If we consider that non-paper components are around 16% of the total unusable materials (ASPAPEL and REPACAR, 2008), the 3.2 points increase in total unusable materials would imply a 0.51% increase of non-paper components in recovered paper of this source and around 0.256% in the furnish of the mill (this source is around 50% of the furnish). For the same typical production of 300,000 metric tons/year with a yield of 82%, this would mean additional 940 metric tons of non-paper components to be landfilled per year. Assuming 40% water content of pulper rejects (Stawicki and Westenbroek, 2005), 1,570 metric tons per year would be landfilled. This means that, assuming a landfill tax of €80/t, additional costs could be estimated as €125,000/year. These costs will increase in the future due to the continuously increasing recovered paper prices and landfill taxes. If the share of non-paper components is important (as occurs with recovered paper collected by commingled systems), additional estimations also taking into consideration the life of certain equipment, higher maintenance costs therefore would be necessary.

The situation is even more complicated if we consider that, at the same time that the quality of recovered paper has deteriorated, an increase in price has occurred because of scarcity of recovered paper due to internal and export demand. Each year, the quality of the recovered paper has been lower, thus increasing the associated manufacturing costs. However, the price of recovered paper has increased continuously. During the period 2005-2008, this price even doubled in Spain and other European countries. Figure 5 shows the evolution of the price of recovered paper per metric ton in Spain for grade 1.01 (mixed paper and board, unsorted) and grade 2.01 (newspapers). The price of grade 1.01 increased from around €25/metric ton during 2005 up to €60/ton during 2007 and 2008. Prices for grade 2.01 increased from around €60 during the first months of 2005 up to €110 in 2007, decreasing to around €85/ton during 2008.

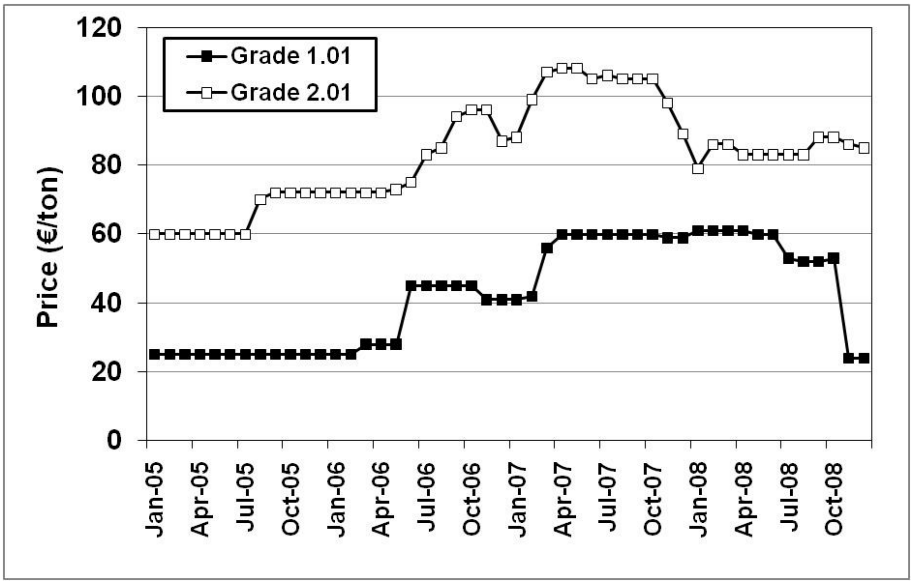

Figure 5.- Price evolution of recovered paper grades 1.01 (mixed paper and board, unsorted) and 2.01 (newspapers) in Spain during the period 2005-2008. Source: ASPAPEL.

3.2. IMPACT OF INCREASED COLLECTION RATES ON MOISTURE CONTENT

Figure 6 shows the annual average of moisture of recovered paper used as raw material at the mill. Moisture of recovered paper has increased from 6.6% in 2005 to 8.3% in 2008, which means almost a 25% increase. To compensate for the increase of the moisture of the recovered paper from 6.6% to 8.3% is necessary to have 1.7% higher consumption of recovered paper. If the same typical newsprint mill producing 300,000 metric tons is considered and the same conditions (82% yield and €100/ton as the price for typical deinking grade 1.11), the additional costs related to an increased moisture content could be as high as €625,000 per year. These costs are so high because the moisture content measured is the average for all the raw materials used at the mill and not only a source of recovered paper, as is the case with unusable material measurements.

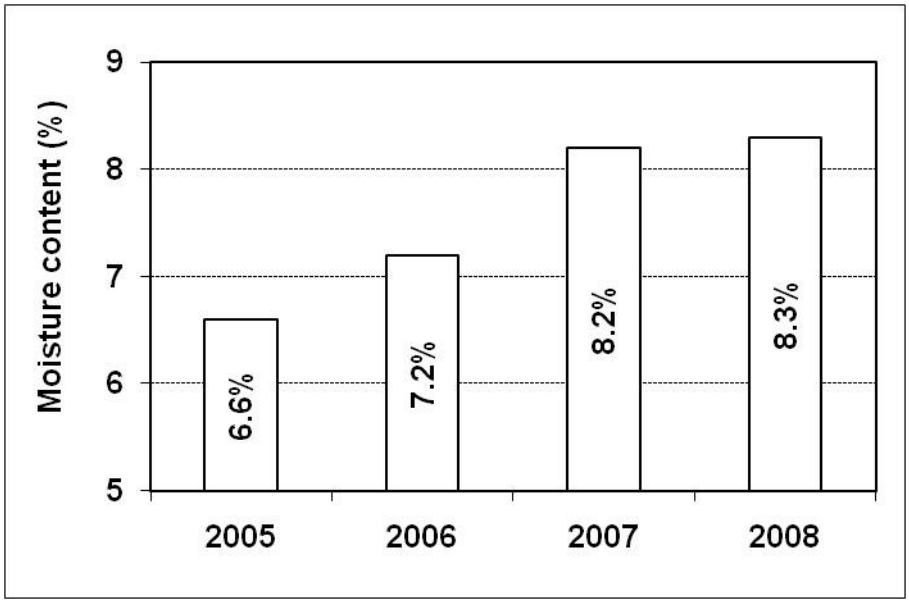

Figure 6.- Moisture content of recovered paper used at the mill. Annual averages from 2005 to 2008.

If monthly averages of moisture contents are calculated, the differences between the seasons can be analyzed (Figure 7). Average moisture is considerable lower during the summer (7.5-7.7%) than in winter (8.9-9.7%). Higher moisture content is observed during the period from October to February, which is in agreement with the report from NOVOTEC (2008). Monthly average of moisture is always lower than 10%, but during the end of 2008 and in the first months of 2009 (data not shown), some monthly averages are higher than 10%.

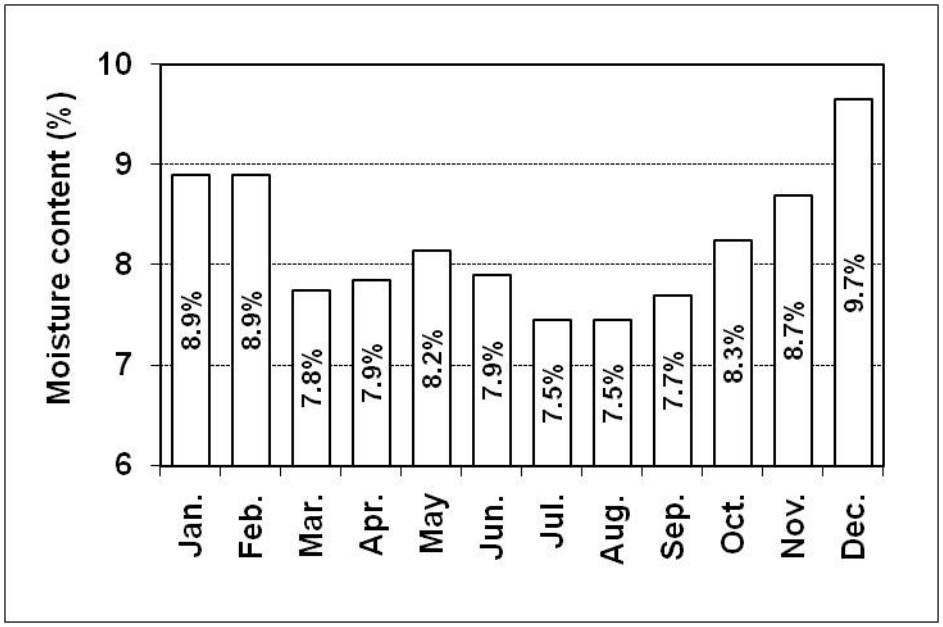

Figure 7.- Monthly average of the moisture content of the recovered paper during the period 2005-2008.

Higher moisture content in recovered paper can be related to different factors. First of all, the climate could be an important issue because bales are stored outdoors.

Recovered paper is a hygroscopic material and important differences in the climate such as the average humidity or temperature of the air could influence its moisture. In fact, average moisture content of recovered paper during cold and rainy months can be between 1.5 and 2.0% higher than in the case of hot and dry months (Figure 7). Monthly humidity, temperature and precipitations have also been analyzed together with the moisture of the recovered paper and partial correlation has been observed, especially with average humidity. For example, 2005 was a very special year: the second year with less average humidity of the decade (52.7%) and the driest year (216 mm of precipitations), while average humidity in period 2006-2008 was 56.5% and 371 mm of precipitations. This could justify the lowest moisture content of recovered paper in this year. However, during the period 2006-2008 the climate was very similar: average humidity of air varied between 56.4% and 56.5% and precipitation from 331 and 393 mm. However, the average moisture content in 2006, for example, is around 1.0% lower than 2007 and 2008. This means that climate conditions are one issue but not the only factor to explain the observed variations on moisture content during the years.

Higher moisture contents in the recovered paper can be influenced by some other factors, for example one of the most important is the use of more contaminated sources such as recovered paper collected from households. The high quality sources, those available in higher volumes and the less contaminated, are the first exploited sources. However, higher collection rates are achieved only through collection of more disperse and from lower quality sources, in which the recovered paper is more contaminated e.g. with food remains, making the recovered paper wet and smells. This is very common in recovered paper from commingled collection systems (White, 2007). Recovered paper obtained from unsold newspapers or magazines has a very lower amount of contaminants compared to those obtained from households.

In addition, the higher presence of board in the recovered paper used as raw material can be another influencing factor, although its importance seems to be rather low due to the proportions found in the deinking grades. It has been previously reported that moisture of board is usually higher than deinking grades such as ONP and OMG. Bösner et al. (2008) found, for example, that average moisture content for grade 1.04 (supermarket corrugated paper and board) was 10-15% while grades 1.11 (sorted graphic paper for deinking) or 2.01 (newspapers) have an average moisture content of 10%. In addition, intermediate grades such as 1.01 or 1.02 (mixed paper and board), have intermediate moisture content between 10-12.5%. The same was also observed in a Spanish board mill where grade 4.02 (kraft board) has, on average, 1.9% higher moisture content than grade 1.01 and 1.0% higher than 1.02. Grade 1.04 has, on average, 1.1% higher moisture than grade 1.01 and 0.3% higher than grade 1.02 (ASPAPEL and REPACAR, 2008). However, an increase in the total unusable material from 5.5% to 8.7% (mainly board) would not explain such big differences in the moisture content observed in the data presented.

3.3. RELATIONSHIP BETWEEN THE UNUSABLE MATERIAL AND MOISTURE CONTENTS AND THE INCREASED COLLECTION RATES

As a summary of the influence of collection rates on the quality of recovered paper, unusable material and moisture content have been analyzed together with the collection rate of recovered paper in Spain during the same period (Figure 8). A very clear

relationship between the increase in the recovered paper collected and the quality of the collected recovered paper has been observed. In the case of total unusable materials, the coefficient of correlation of the linear fit is R^2=0.957 and the p-value is 0.0216. These values indicate a strong relationship between these variables: the linear fit explains more than 95% of the variability of the unusable material contents and there is a statistically significant correlation between these variables at the 95% confidence level. In the case of moisture, the coefficient of correlation of the linear fit is R^2=0.801 and p-value=0.1052. This means that the model does not shows a statistically significant correlation at 95% confidence level; the model only explains 80.1% of the variability of the moisture content values. This corroborates that there is a relationship between moisture content and collection rates but there are some other factors influencing these values, e.g. climate conditions.

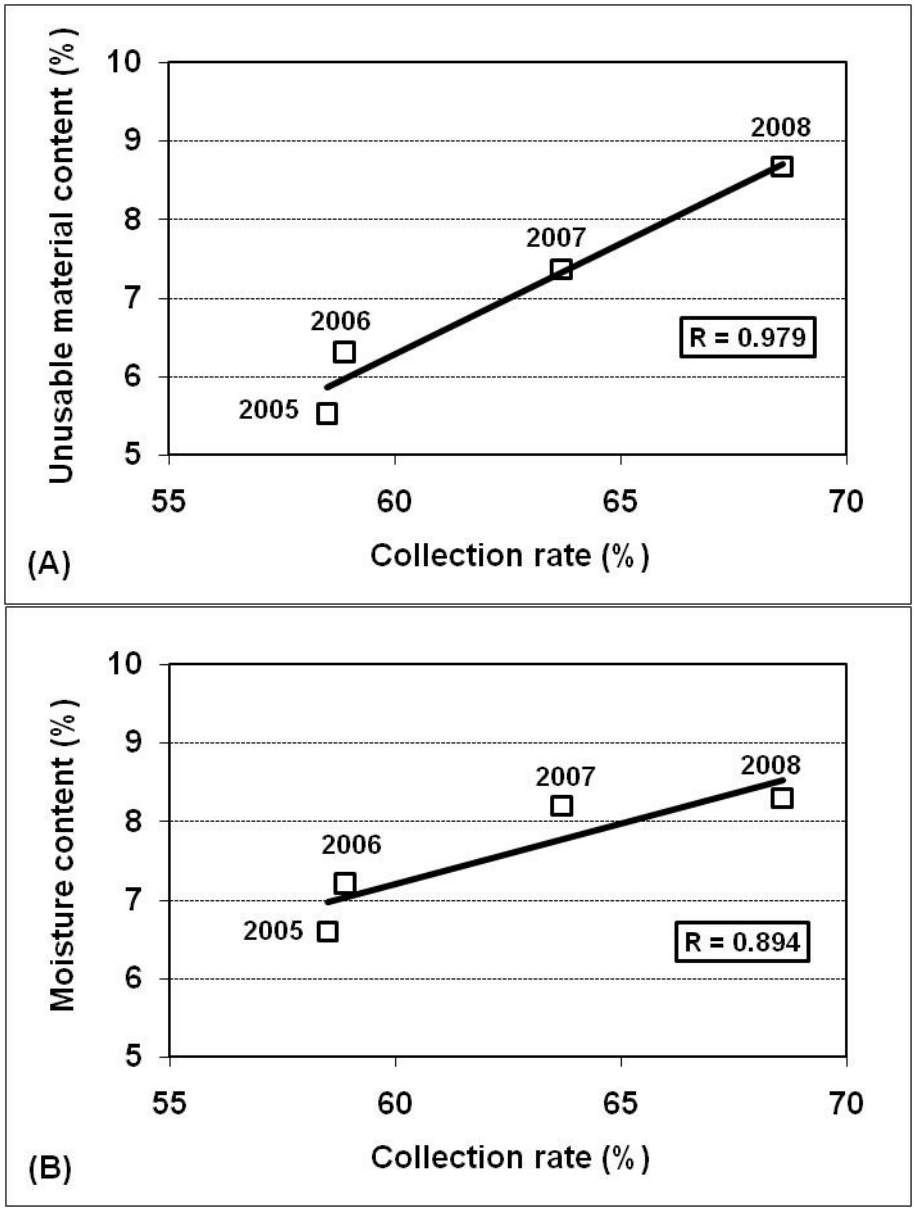

Figure 8.- Correlation between total unusable material content in the recovered paper from households collection (A) and the moisture content of the recovered paper used by the mill (B) and the collection rate of recovered paper in Spain during 2005-2008.

These results confirm the generally-known fact that the increase of the availability of recovered paper usually implies a lower quality of the recovered paper. As mentioned before, only if significant differences in collection rates occur, would it be possible to study the progressive deterioration of the quality of recovered paper otherwise if collection rates increase very slowly it would be difficult to monitor the quality over substantial periods of time. In addition, the collection rate has been demonstrated to be a good indicator to analyze the degree of exploitation of the recovered paper sources.

4. CONCLUSIONS

This study has demonstrated and quantified the importance of downgrading of the recovered paper when the collection rates increases significantly. The increase in collection rate from 58.5% to 68.6% in only four years (2005-2008) produced an increase in the total unusable material content from household collection from 5.5% to 8.7% while at the same time, the moisture of the recovered paper increased from 6.6% to 8.3%. This means a 57% increase in unusable material content and 26% in moisture content in only four years. A strong correlation between the unusable material content and the collection rate has been observed ($R=0.979$, p-value<0.05). In the case of the moisture content, the general trends are followed but other factors such as climate conditions have to be considered together with increased collection rates ($R=0.894$ and p-value>0.05).

Other studies have not observed such rapid deterioration of the quality of recovered paper but the quality remained relatively constant (Neukum et al., 2001; Faul, 2005; Bösner et al., 2008). These studies, however, were mainly carried out within the German paper industry or through the International Deinking Association (INGEDE), who traditionally were mostly formed by paper mills from Germany or Central Europe. In these countries, the collection of recovered paper has been well developed for many years, and the annual increases of the collection rates are marginal. For example, in Germany the collection rate has increased from 69.9% to 74.1% in the 1998-2008 period while in Spain this has increased by more than 25 points. More than 10 points in the 4-year period analyzed in this work.

The new Waste Directive in Europe has reached a milestone. The Waste Directive is expected to have an important influence on the quality of recovered paper to be available in the market with the help of the end-of-waste criteria. Due to the potential benefits which can be expected by the recovered paper ceasing to be considered as waste (legal, economic, etc.), further efforts are expected to be made at all levels of the recovered paper value chain to reduce the total unusable materials to 1.5% or less. In addition, the new Directive minimizes the threat of spreading even more the use of commingled collection systems to other countries in Europe by promoting the selective collection of all the recyclables, including targets (Part 2 of this work).

The promotion of recycling has many environmental benefits but the volume of paper collected need to be addressed together with its quality. In fact, the low quality of recovered paper is one of the limiting factors for extending the limits of paper recycling. For this reason, it is necessary to further improve the development of environmental awareness by people leading them to better sort waste at source; the use of selective collection systems, instead of commingled collection systems, for a lower degree of

contamination; and the development of advanced sorting techniques, to remove more efficiently the contaminants and at lower costs.

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5. LITERATURE

ASPAPEL and REPACAR, 2008. Determination of the composition of materials and moisture content of recovered paper and board. Madrid (Spain) [in Spanish].

Blanco, A., 2003. Microbiology in papermaking, in: S.G. Pandalay (Ed.), Recent Research Developments in Applied Microbiology and Biotechnology Vol. 1, Research Signpost, Trivandrum (India), pp. 87-134.

Bösner, J.-K., Hirsch, G., Putz, H.-J., Weinert, S., 2008. Quality properties of the most important recovered paper grades in dependence of sorting conditions (AiF-Project 15408 N)". In: COST E48 Meeting, Budapest (Hungary), 15-16 May.

CEPI, 2010. 2009 CEPI Key Statistics. CEPI, Brussels (Belgium).

Clapp, D., 2006. Single-stream collection systems offer obstacles and opportunities. Pulp Pap. 80(6), 36-37.

De Feo, G., De Gisi, S., 2010. Public opinion and awareness towards MSW and separate collection programmes: A sociological procedure for selecting areas and citizens with a low level of knowledge. Waste Manage. 30(6), 958-976.

Emerson, D., 2004. Single stream vs source separated recycling. Biocycle 45(3), 22-25.

EN 643: European List of Standard Grades of Recovered Paper and Board, 2002. European Committee for Standardization. Brussels (Belgium).

ERPC (European Recovered Paper Council), 2006. European Declaration on Paper Recycling 2006-2010. ERPC, Brussels (Belgium).

ERPC (European Recovered Paper Council), 2010. European Declaration on Paper Recycling 2006-2010: Monitoring Report 2009. ERPC, Brussels (Belgium).

European Parliament and Council Directive, 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives. Official journal of the European Union L312, 3-30 (22.11.2008).

Fairbank, M., Keenan, D., Peters, H., Prein, M., Schwarzbach, A., Wells, L., 2006. Effect of recovered paper quality and deinking process parameters on dirt levels in newsprint. Pulp Pap. Can. 107(12), 64-67.

Faul, A., 2005. Quality aspects of recovered paper for deinking. Prog. Pap. Recycl. 15(1), 6-10.

Faul, A., 2009. Graphic paper recycling – markets and quality requirements. In: COST Action E48 Final Conference: The limits of paper recycling, Munich (Germany), 6-7 May.

Faul, A., 2010. Quality requirements in graphic paper recycling. Cellul. Chem. Technol. 44(10), 451-460.

Kinsella, S., Gertman, R., 2008. Single stream recycling best practices manual and implementation guide. Prog. Pap. Recycl. 17(3), 6-8.

Levlin, J.-E., Read, B., Grossmann, H., Hooimeijer, A., Ervasti, I., Lozo, B., Saint-Amand, F.J., Cochaux, A., Faul, A., Ringman, J., Stawicki, B., Bobu, E., Miranda, R., Blanco, A., Stanic, M., 2010. COST Action E48 - The future of paper recycling in Europe: opportunities and limitations. COST, Brussels (Belgium).

Miranda, R., Blanco, A., 2008a. Paper recovery in Spain. Ingeniería Química 464, 130-139 [in Spanish].
Miranda, R., Balea, A., Sanchez de la Blanca, E., Carrillo, I., Blanco, A., 2008b. Identification of recalcitrant stickies and their sources in newsprint production. Ind. Eng. Chem. Res. 47(16), 6239-6250.
Miranda, R., Bobu, E., Grossmann, H., Stawicki, B., Blanco, A., 2010a. Factors influencing a higher use of recovered paper in the European Paper Industry. Cellul. Chem. Technol. 44(10), 419-430.
Miranda, R., Blanco, A., 2010b. Environmental awareness and paper recycling. Cellul. Chem. Technol. 44(10), 431-449.
Miranda, R., Blanco, A., 2010c. Influence of pulping chemistry on the release of contaminants in recycled paper production. In: PTS Symposium Applied Interface Chemistry, Munich (Germany), 9-10 February.
Miranda, R., Blanco, A., 2011. Impact of increased collection rates and the use of commingled collection systems on the quality of recovered paper. Part 2: Use of commingled collection systems. Waste Manage. (under review).
Monte, M.C., Fuente, E., Blanco, A., Negro, C., 2009. Waste management from pulp and paper production in the European Union. Waste Manage. 29(1), 293-208.
Neukum, P., Renner, K., Putz, H.-J., 2001. Effect of paper collection on recovered paper characteristics and DIP quality. In: 5th CTP/PTS Advanced Training Course on Deinking, Grenoble (France), 23-26 March.
Patrick, K., 2006. Stickies, still a critical concern for today's recycling plants. Pap. Age 122, 28-31.
Read, B., 2009. The future of recovered fibre in the UK. In: COST Action E48 Final Conference: The limits of paper recycling, Munich (Germany), 6-7 May.
Roring, A., Soede, O., Hegdal, A., Rangul, B., 2006. In: 12th PTS-CTP Deinking Symposium Proceedings. Leipzig (Germany), April 25-27.
Sacia, W.K., Simmons, J., 2006. The effects of changing ONP quality on a newsprint mill. Tappi J. 5(1), 13-17.
Schmidt, J.H., Holm, P., Merrild, A., Christensen, P., 2007. Life cycle assessment of the waste hierarchy – a Danish case study on waste paper. Waste Manage. 27, 1519-1530.
Spiess, W., Renner, K., 2004. Improving the efficiency of recovered paper screening or how to effectively control stickies. Wochenbl. Papierfabr. 132(17), 1002-1009.
Stawicki, B., Westenbroek, A., 2005. Composition of coarse rejects. Inventory in the Dutch recycled paper mills. In: COST E48 Meeting, Brussels (Belgium), 28-29 November.
Strunz, A.-M., 2005. Recovered paper grades for the production of packaging papers. In: COST E48 Meeting, Brussels (Belgium), 28-29 November.
Villanueva, A., Eder, P., 2011. End-of-waste criteria for waste paper: technical proposals. Final report. Institute for Prospective Technological Studies, European Commission, Seville (Spain).
Villanueva, A., Wenzel, H., 2007. Paper waste – Recycling Incineration or landfilling? A review of existing life cycle assessment. Waste Manage. 27(8), S29-S46.
Wagner, J., Franke, T., Schabel, S., 2006. Automatic sorting of recovered paper – technical solutions and their limitations. Prog. Pap. Recycl. 16(1), 13-23.
Wagner, J., Franke, T., Schabel, S., 2007. Automatic sorting of recovered paper: technical solutions and their limitations. Rev. ATIP 61(1), 14-21.
White, C., 2007. Quality matters: the mill buyer's perspective. In: European Paper Recycling Conference. Amsterdam (The Netherlands), 3-5 October.
WRAP (The Waste and Resources Action Programme), 2004. Optimising the value of recovered fibre. Oxon (United Kingdom).