Determination of Moisture Content of Recovered Paper Bales

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"Lidé se obávají neznáma. Jest pravda, že každé opuštění starého znamená nejistotu - skok do tmy. Avšak kdo chce pomoci sobě a jiným, musí opustit dobré, aby mohl vybojovat lepší. Nesmí držeti pevně vrabce v hrsti jen proto, že je lepší než holub na střeše. Bez odvahy ke změně není zlepšení, a tak není ani blahobytu!"

"Když všichni mluví o nemožnostech, hledej možnosti."

"Co chceš, můžeš!"

"People are afraid of an unknown. This is truth, that it brings the insecurity. When we leave "the old one", it is like a jump into the dark. However, if we want to help us or to help others, we must to leave "the good one" and to gain "a better one". We cannot keep a bird in a hand, just because those two birds in a bush are uncertain. Without the courage of change, there is no improvement and neither the prosperity."

"When the others are speaking about impossibility, you look for possibilities."

"Everything you do want, you can!"

Tomas Bata (1876 – 1932)

ABSTRAKT

Diplomová práce se zaobírá determinací vlhkosti balíku sběrného papíru. Zaužívaná metoda založená na vzorkování balíků a sušení vzorků se ukázala jako nevyhovující pro tak velkou a nerovnoměrnou masu papíru. Z tohoto důvodu byl započat výzkum s cílem vyvinout nový komplexní přístup k determinaci vlhkosti balíku separované papíru, který si zakládá na lineární závislosti vlhkosti a hustoty balíků sběrného papíru.

Klíčová slova: Vlhkost, Hustota balíků sběrného papíru, Měření vlhkosti papíru.

ABSTRACT

The master thesis collaborates about moisture content determination of recovered paper bales. Conventional sampling of oven-dried method brings a high deficiency of moisture content estimation and it was evaluated as a non-compatible method for such a huge non-uniform mass. The aim of this research was to develop a new complex approach, which is based on the bale density and moisture content linear regression.

Keywords: Moisture content, Bale density, Recovered paper, Moisture determination.

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I hereby declare that the print version of my Master's thesis and the electronic version of my thesis deposited in the IS/STAG system are identical.

CONTENTS

INTRODUCTION

The thesis is divided into theoretical and analysis parts. The first part cooperates with a brief papermaking description. Paper as matter is a very unique material within special properties. The most important properties are defined in the followed chapter. The theoretical part is closed by the European and worldwide overview of recovered paper production, consumption, trade market, and recovered paper prices.

The second part is focused on the moisture content of recovered paper bales. Presently, the oven-dried method is used for moisture content determination, which shows deficiencies. Several experiments were performed, which are focused on the determination of these deficiencies. The theoretical assumption of the moisture/density function was researched in a laboratory. Various types of bale model experiments were performed within various changes of moisture content and oven-dried mass. According to the experiments, it was designed a new approach of moisture content determination, which works on the linear regression of moisture/density linear regression.

I. THEORY

1 PAPER AND PAPERMAKING

Paper is made from plant fibres called cellulose, which can be found in wood as a structural component. Cellulose is an organic compound consisting of a linear chain. Despite of this fact, cellulose is categorized as an organic polymer.

The wood matter is essential to convert into pulp before being used to manufacture paper. Virgin pulp is a fibre mass, which is made of wood. There is also recycled pulp, which is recovered from the waste paper.

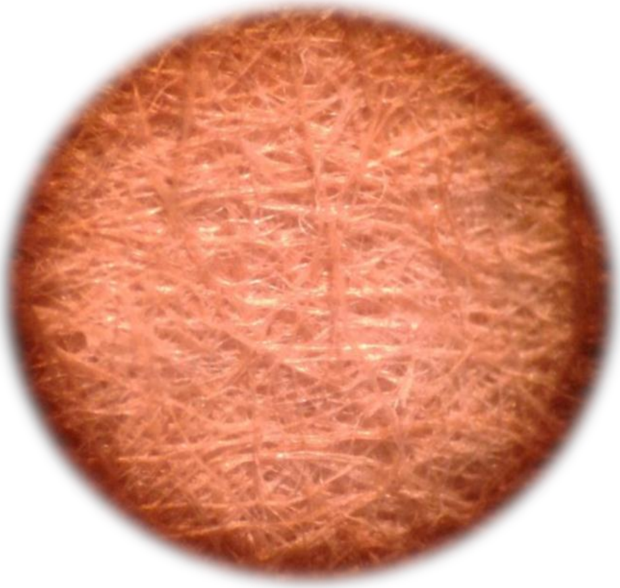

Figure 1. Virgin pulp on the microscope view.

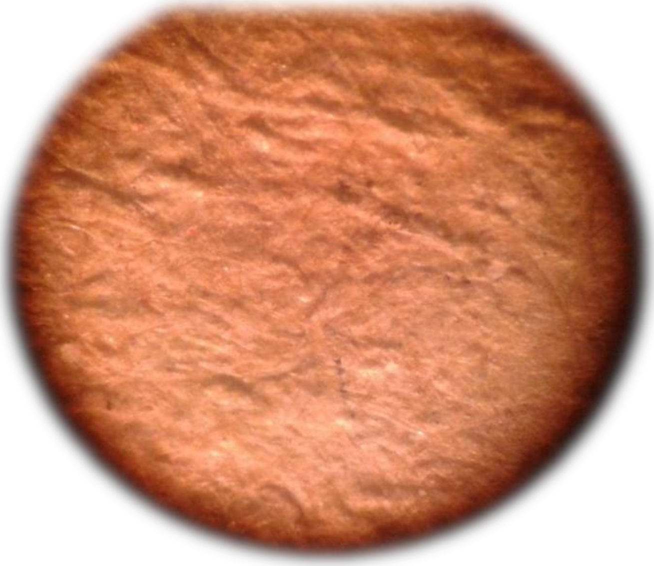

Figure 2. Manufactured paper on the microscope view.

Paper is widely known as a thin material. Its inhomogeneous structure can be described as the stochastic network of fibres, which are much longer than the thickness of paper sheet. Base on this fact, paper is simplified and considered as a two-dimensional matter.

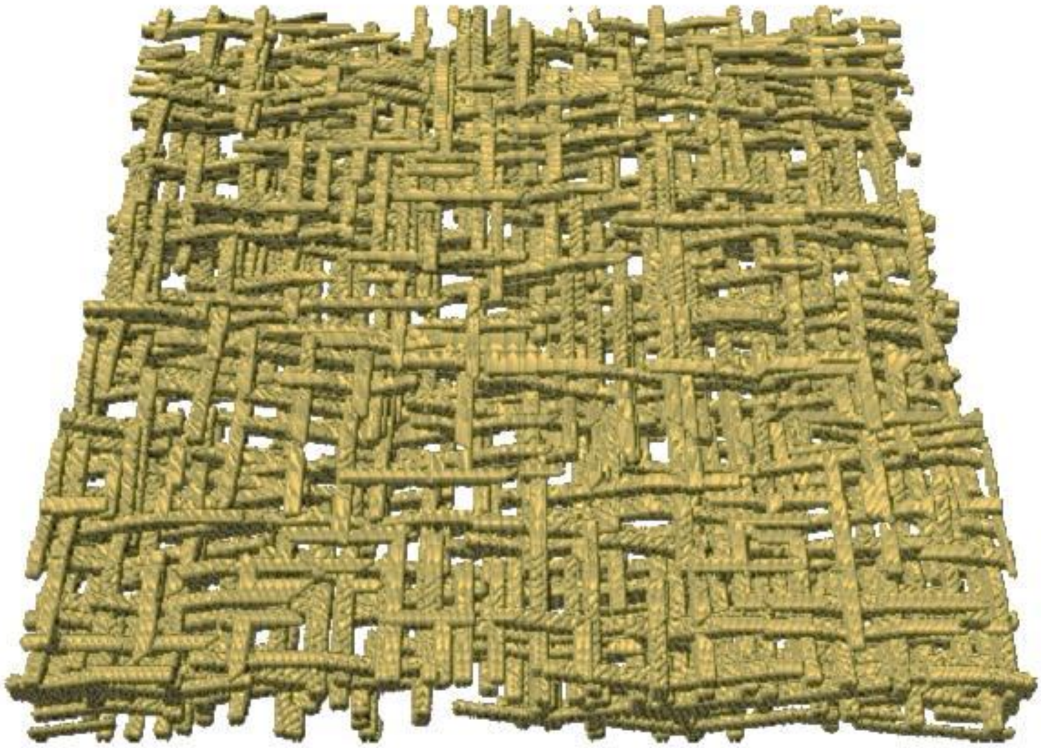

Figure 3. Model of 2D fibre network with obvious porosity. [4]

1.1 Paper and Board Grades

Paper material is common material in daily life. It can be used for many purposes. The main categories of paper products include:

- Packaging grades.
- Graphic paper grades.
- Tissue paper.
- Speciality papers.

Figure 4. Variety of paper products.

In addition to these paper products, the industry is increasingly producing high value-added products and sophisticated materials for the textile, food and pharmaceutical industries, as well as bio-based fuels and chemicals.

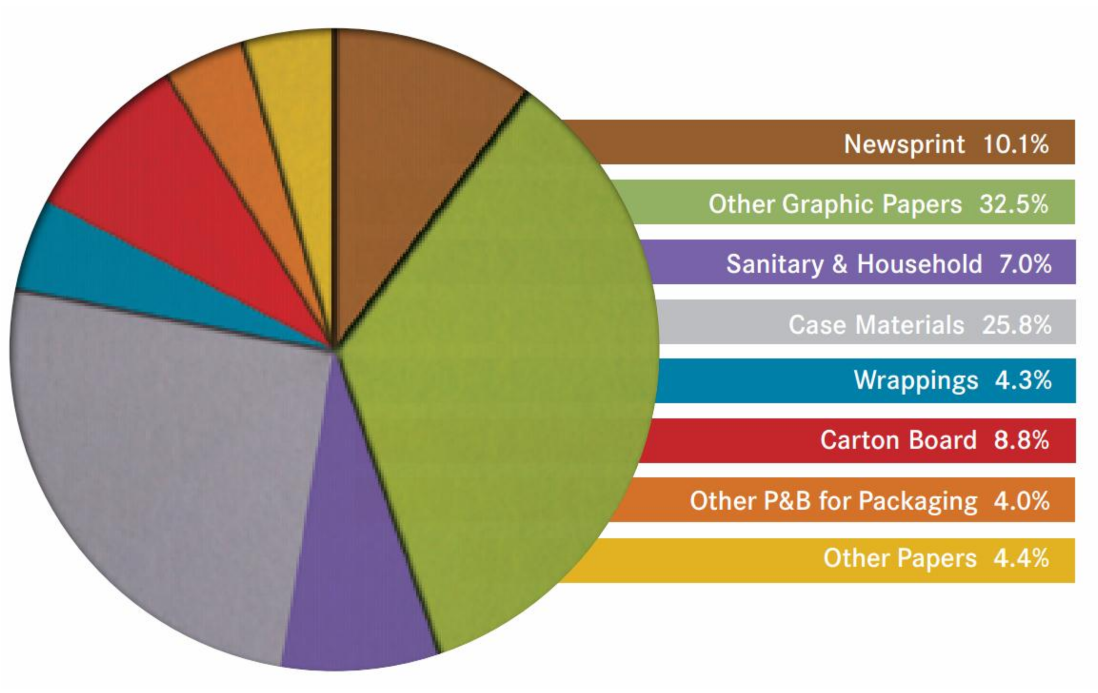

Figure 5. CEPI paper and board production by grade in 2010. [7]

The Figure 5 shows the paper manufactured in CEPI countries (17 EU countries + Switzerland and Norway) by grade. The majority represents the packaging grades (38.6%), which are the case material, the carton boards and other P&B packaging. Second major group are the graphic grades (32.5%). Tissue paper and speciality paper are produced of smaller quantities.

1.1.1 Packaging Grades

They could be called also paperboard grades. Their perspective consists on packaging use. Usually basis weight of paperboards reaches 150 g/m^2 and more. Because of the high basic weight, strength properties are increased.

- Carton boards – the products such as food, cigarettes, milk and pharmaceuticals are packed to the carton boards. For various purposes, carton boards have to meet requirements such as mechanical properties, purity and cleanliness, printing properties.
- Container boards – corrugated boxes are used in wide field of packaging and logistic. This type of paperboard grade represents large share of world paper and board material. Corrugated board is folded to the corrugate packages and consist of linerboard/corrugated medium/linerboard. Mechanical properties are its advantages, when the sandwich effect is applied. Another benefit is sustainability. Old boxes are recycled with high efficiency for linerboard or corrugation medium. Waste paper bales in Europac Kraft Viana are mostly composite of old corrugated boxes and accordingly renewed for kraftliner and testliner products.
- Special boards - such as wallpaper base, core board, plaster board. There are used as a building material or decoration material. Core board are used for cores of rolled bales, which are produced from recycled material. Special boards can be classified as a speciality papers as well. [10]

1.1.2 Graphic Paper Grades

This group contains all printing and writing paper grades, which are used for newspapers, magazines, catalogues, books, commercial printing, copying, business forms, and stationery as well as for laser and digital printing. They cover about 42.6 % of Europe's paper and board markets as the Figure 5 shows. Nowadays, these grades are facing of challenges, because of IT technology and ecological impacts.

There are categorized by the nature of the main raw material (pulp), thus there are 2 groups:

- Mechanical pulp dominating paper – newsprint grades, SC paper grades and coated mechanical grades which mostly contain more than 25 - 50% of mechanical pulp. The advantage is the good opacity and printability even at low basic weights. [10]
- Chemical pulp dominating paper – uncoated or coated fine paper grades, which generally contains maximum 10% of mechanical pulp. Their advantages are strength, high brightness and good archival characteristics. [10]

1.1.3 Tissue Papers

They are used mainly for hygienic purposes. Tissue products cover toilet paper, kitchen towels, handkerchiefs, facials, napkins, hand towels and wipes. They could be produces by virgin or also recycled fibre. Properties of tissues products provide good tensile strength, surface softness, clearness and high ability to absorb liquids. The use of tissue paper products is biodegradable, thus doesn’t harm the nature in waste context. On the other hand, the lifelong of tissue product is very short. [10]

1.1.4 Speciality Papers

They are papers, which have a specific characteristic required for the specific purpose. Continually, the speciality papers are produced in low scale in comparison with packaging, graphics or tissue papers. For instance this group cover electrical papers, cable papers, capacitor tissue, conductive paper, building papers, cigarette papers, filter paper, special strong paper etc. Universally, a speciality paper typically has a set of characteristics, needed for particular use. It has increased performances such as mechanical strength, mechanical structure, absorption, functional characteristic, electrical characteristics, cleanliness or appearance. [10]

1.2 Papermaking process

Wood represents the raw material, which is acquired from natural sources. Mostly are used spruce, pine, fir, larch, hemlock (softwood) and aspen, birch, eucalyptus (hardwood). As secondary raw material, the recovered paper is collected and prepared for recycling process. Wood logs are cut for about four metres and processed through debarking drum.

The logs are cleaned off the bark. Afterwards, logs are cut by spinning blades in chipping machine. Small wooden chips are outcome of the process.

After chipping, the cellulose fibres are separated to each other and the lignin is broken down of fibre walls. Lignin can be described as a “glue” (organic polymer), which hold single plant fibres together. The end product of the process is pulp mass contained virgin fibres. Recovered paper is passing by cleaning processes, when rejects are divided of the recycled fibre. Continuously, the recycled fibre is preceded by deinking stage.

Afterwards, the pulp is refined to demanded length. The pulp fibres are washed and separated of chemicals. In screening stage, the pulp mass is dropped onto continues moving screen which is made of wires. Until now, the water works as mobile medium during all the papermaking process. When the pulp mass is entering paper machine, the water has to be removed. Inside a large rollers, pulp mass is squeezed. This pressure and temperature remove the water, which can be used as pressure steam for producing the electricity. The paper is moulded in paper machine. Finally, produced paper is wrapped on bales, stored in warehouse and delivered to the costumer. This process is shown in the Figure 6. [9]

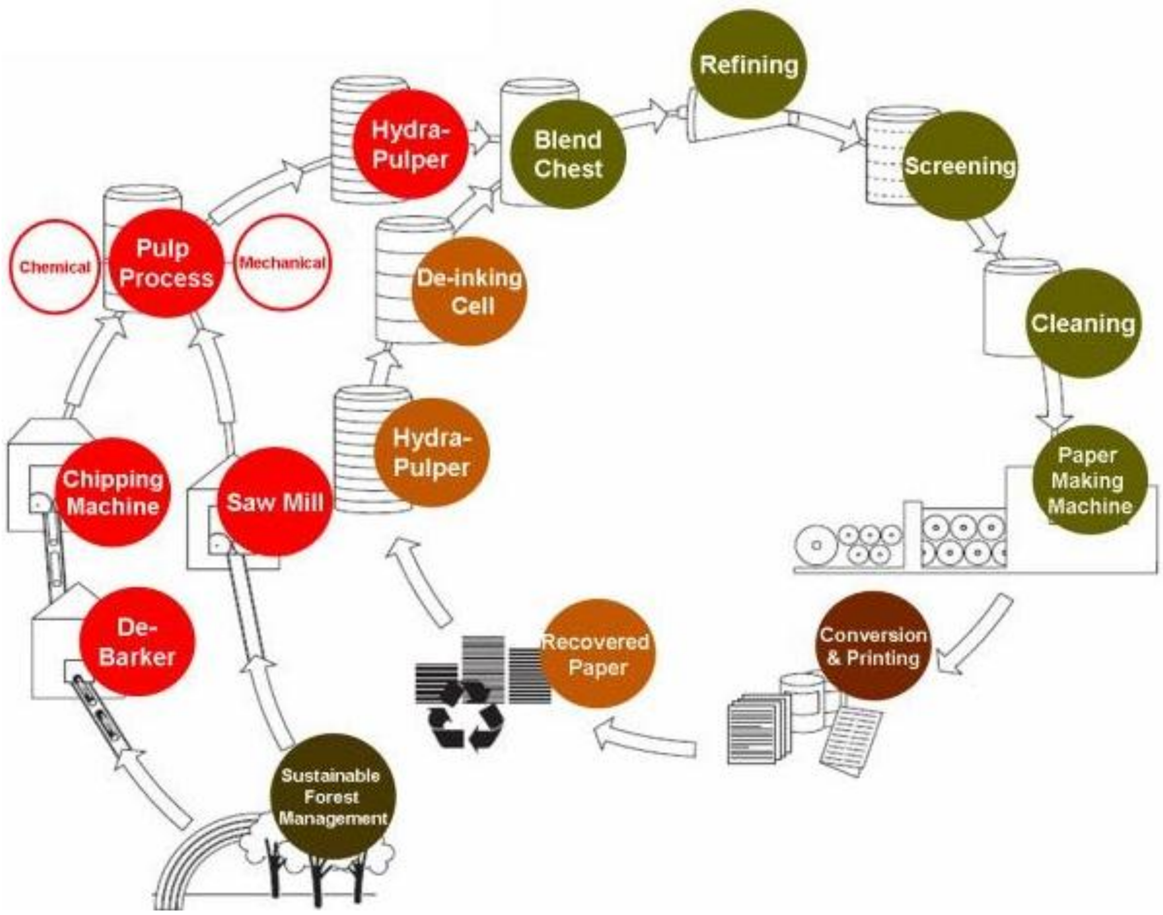

Figure 6. Papermaking process. [8]

1.3 Pulping and pulp matter

Pulp is a product of pulping process, which purpose is to separate the fibres from the wood and to make fibres suitable for papermaking. During this process, it is important to dissolve the bounds between fibres, which are made by lignin. There are various pulping processes, but the two most represented are:

- Mechanical pulping.
- Chemical pulping.

1.3.1 Mechanical pulping

The final product of this process is mechanical pulp. This final matter is reached without any chemical influence or just its minimal use. Papermaking knows many mechanical pulping approaches, nowadays are the most common:

- *Stone Groundwood (GW)* - atmospheric grinding of logs using a pulpstone. The temperature of the shower water normally 70°C - 75°C. Yield 98.5%. [11]
- *Pressure Groundwood (PGW)* - logs are ground in pressurized conditions (2.5 bar) with a Valmet grinder at shower water temperatures lower than 100°C. Yield 98.5%. [11]
- *Thermomechanical Pulp (TMP)* - chips are preheated with (pressurized) steam and refined under pressure at elevated temperatures. The steam (over)pressure is normally 3-5 bar and the steam temperature is correspondingly 140°C-155°C. Yield 97.5%. [11]
- *Chemithermomechanical Pulp (CTMP)* - Pressurized refining of chemically pretreated chips or coarse pulp. Relatively mild treatments. Yield typically over 90%. [11]

<u>Advantages of the mechanical pulping are [11]:</u>

- High pulp yield $\Rightarrow$ more paper can be produced out of limited resources.
- Mechanical pulp is beaten during this process.
- Low capital costs and uncomplicated process with comparison of chemical pulping.
- Good properties such as a high light-scattering power, a fairly high brightness, a high smoothness, a good formation, and a high bulk.

Disadvantages of the mechanical pulping are [11]:

- High electric consumption
- Requirement of high quality wood raw material.
- Lower overall strength properties of paper bonds.
- Impossibility of as high bleached level as chemical pulp.

Paper produced from mechanical pulp can be implicated as various graphic papers, various board grades, wallpaper, fine papers, soft tissue, and absorbent and moulded products. [11]

1.3.2 Chemical pulping

Debarked wood is cut into chips and screened Afterward there are chemically threaded to form fibrous matter, which is called chemical pulp. Lignin is dissolved from wood chips in digester, during the coking. It consist influence of chemicals, temperature and the water. There are two chemical pulping approaches [12]:

- *Alkaline sodium processes* – produces brown, strong and flexible fibres.
- *Acidic sulfite processes* – produces lighter, weak, stiff and brittle fibres.

Advantages of the chemical pulping are [12]:

- Better lignin dissolving – approximately 10% of the pulp.
- Variable wood resource and paper produced.
- Increasing pulp strength.
- Better heat and chemical recovery ⇒ financial savings.
- Chemical pulp could be bleached during this process.

Disadvantages of the chemical pulping are [12]:

- Low pulp yield – about 60%.
- High pollution.

Chemical pulping provide pulp for production of any kind paper product. [12]

1.4 Recovering a fibre from waste paper

Recycled pulp is created by recycled fibre. There are two differences between source of virgin fibre (chemical and mechanical pulping) and recycled fibre:

- Recovered paper is a usually mixture of various fibre types or paper grades.
- Occurrence of contaminants and other detrimental substances:
  - Additives, which were used in previous paper production process such as fillers and dyes, coating components and functional and process chemicals.
  - Substances, which were added according to application such as printing inks, coatings, foil laminations, and adhesives.
  - Solid rejects, which were mixed with the paper during its life cycle and subsequent collection including wires and strings, sand and stones, or paper clips and folders. [1]

Nowadays the EU pushes paperboard producers to reach very high ration of recovered fibre. In high developed mills, recycled fibre largely or completely replace the various kinds of virgin fibre in many paper and board grades. Thus this process of recovering waste paper is important to proceed effectively. [1]

After slushing, the recovered mass is separated. It can be provided by several processes with following characteristics:

- Screening - particle size, shape, and deformability.
- Washing - particle size and shape.
- Centrifugal cleaning - specific gravity, size, and shape of particles.
- Flotation - surface properties and size of particles. [1]

During these processes, it is very difficult to separate small, flat and deformable particles. At least, those metal pieces are possible to divide with magnet technology. [1]

Besides separation, there are other important processes for recycled fibre preparation:

- Slushing and deflaking: breaks down the recovered paper first into a pumpable condition enabling coarse separation that is normally included in this stage and then by deflaking if necessary.
- Fractionation (a special kind of screening): separates a fibre mixture according to defined criteria such as size or deformability.

- Dispersing and kneading: makes residual dirt specks and stickies smaller or floatable, detaches ink still adhering to the fibres, mixes in bleaching agents, and conditions the fibres technically.
- Refining: modifies the fibre morphology and surface characteristics to ensure the required bonding properties and paper quality.
- Dewatering (thickening and pressing): removes water from the suspension making certain processes possible such as dispersing or more cost-effective such as bleaching or storage (Drainage also separates the water loops for ionic trash and temperature control).
- Bleaching: endows yellowed or coloured (brown) fibres with the required brightness or luminance.
- Storing and mixing: suspension components prevention of demixing or mixing them together. [1]

1.4.1 Deinking

Deinking is the process of purifying the recovered fibre. Graphic grades contain ink as a printing media, which is removed for reaching better quality of recovered paper. Deinked paper has low brightness and dirt specks. The efficiency of ink separation depends on the ink properties.

There are two approaches the ink separation:

- Flotation – as a most common technique. It provides high fibre yield, low amount of rejects, less efforts of purify the reject water.
- Washing – when ink particles are separated according to their size. The technique is used for low ash tissue paper. [1]

1.5 Refining, Screening, Bleaching

The pulp mass is treated for improving their properties, such as:

- Refining (beating) – is designed for improving a bonding ability of fibres. This process makes fibres ends divided (fibrillation). It helps to form strong and smooth paper sheet with good printing properties. Porosity of paper is decreaset.
- Screening and cleaning – Pulp stock contains unwanted impurity (bundles, flakes, debris, strings), which has to be removed before paper manufacturing.

- Bleaching – is a process, which improves the optical properties (brightness, luminance) of the paper. Mostly is used for the recycled pulp. [1]

1.6 Waste paper quality control

Waste paper is delivered in pressed form of quadratic bales. The composition is very heterogeneous and bales contain non-fibrous materials and rejects. In comparison with data from 1980's, the amount of rejects have risen during past years

The European EN 643 Standard [6] describes into the detail, how grades differ to each other. Generally, they could be divided to:

- Ordinary grades.
- Medium grades.
- High grades.
- Kraft grades.
- Special grades.

After delivering bales to the paper mill, the quality control of recovered paper is performed. Based on this judgement, most recovered paper is accepted, rejected, or complaints are made to the suppliers. Quality control consists of:

- Moisture content determination – by determining moisture it is described the pure fibre mass.
- Visual inspection – only surface of bales can be checked, whether too contaminated bales are unwanted.

1.6.1 Moisture content determination

Moisture content of recovered paper bales depends on:

- Material composition such as type of fibre furnish, recycled fibre content, and ash content.
- Climatic conditions during collection, transport, baling, and storage of the recovered paper.
- Storage conditions of the recovered paper (outdoors, under cover, or in enclosed facilities). [2]

Because of stated reasons, MC of recovered paper is higher than the norm value of 10% ±2% [6]. The real MC is necessarily to check on the delivering to the paper mill. The challenge of an adequate moisture content determination always exists, whether the MC is possible to estimate only. There are various techniques in use:

- Samplings techniques – about 0.3 – 3.0 kg of samples are taken from inner part of bale. These samples are placed to the oven (105°C) for 24 hours. By the difference mass weights the moisture content is determinate. Bales are usually opened and samples are taken from the middle of mass. Another option is to use the drill machine, which makes a hole into the bale and continuously separate amount of samples from the middle.
- Devices techniques - the measurements use principle of conductivity, electrical resistance, or the dielectric characteristic. Values are recorded very quickly for calculating average MC of recovered paper delivery. Such devices do not provide absolute values. The coefficients of variation of these measurements compared with gravimetric moisture content determination are considerably greater. [2]

2 PAPER STRUCTURE AND PHYSICS

For well understanding paper material, it is necessarily to describe structure of paper, fibre matter and physics of fibre. [2]

2.1 Fibre characterization

Paper is basically the net of fibres, randomly aligned on the plane. Fibre has a spiral profile whether it's width and high is much smaller than length. At the same time, a fibre length is always longer than papers thickness. In addition to fibres, paper consists of fibre fragments, mineral fillers, and chemical additives. Closer look to the fibre characterisation describes Figure 3 and Figure 7. [2]

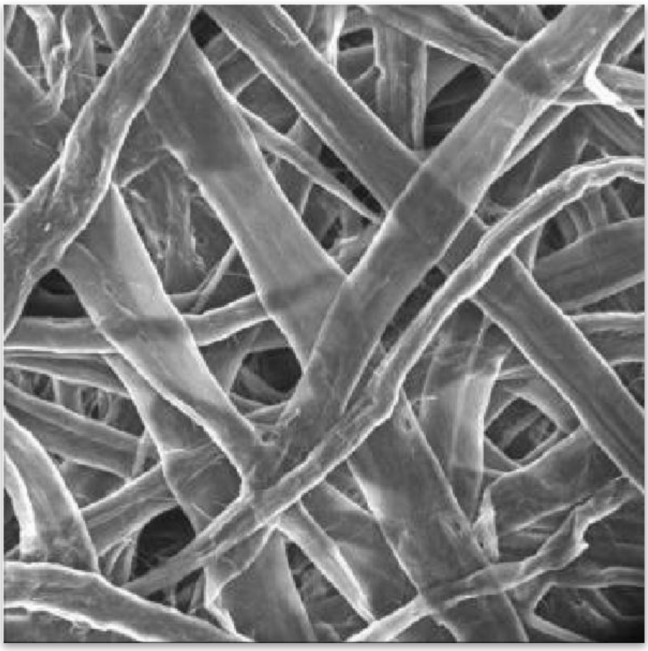

Figure 7. Scanning electron microscope image of a paper surface (KCL).

2.1.1 Fibre types

There are two types of fibres:

- Virgin fibre – made of wood by chemical or mechanical pulping.
- Recycled fibre – recovered form waste paper.

Generally recycled fibre is shorter, stiffer, curlier and more brittle. Correspondingly the fibre recovered from waste paper has lower hygroexpansivity than the virgin fibre. [2]

2.1.2 Network geometry

Since the fibres are much longer than the thickness of the paper sheet, the network is planar and almost two-dimensional. The two-dimensional approximation is valid only with presence of low coverage or with infinitively high fibre flexibility (both cases minimize pores existence). Real paper is three-dimensional with a finite thickness and z-directional pores. The pores ignored in the two-dimensional approximation give paper it's opaque, bulky, and stiff structure. The pathwork of pores determines how fluids transport through the sheet. [2]

2.1.3 Porosity

The porosity determines appearance of pores - vacancies in paper sheet. The average number of pores per unit area grows linearly with basic weight or coverage. Nevertheless, the sizes of the three-dimensional pores in paper are difficult to determinate.

When the higher SR number (level of beating process), the pore number is decreased. These fibres form bulk with smaller pores. Inscribed fibre can absorb water much easier, which helps to transport and control pulp easier. On the other hand, paper drainage section become more complicated, because the water "stacks" in smaller pores and better bended mass does not let evaporate water effortlessly. [2]

2.1.4 Grammage

The paper material is produced in plane form, what influence the paper density consideration. Thus the paper density is used in average mass per unit area, what is also known as basis weight or grammage of paper. Structurally, it is an average mass of fibres per unit area. For instance, kraft paper varies in range of 115 g/m^2 – 275 g/m^2, casual office paper has 80 g/m^2, and tissue paper app. 20 g/m^2. [2]

2.1.5 Relatively bonded area

The connectivity or degree of the fibre network controls the mechanical properties of paper. The network would have no cohesion if there were too few bonds between the fibres. The RBA usually characterizes the bonding degree of paper. By definition, RBA is the bonded surface area of fibres divided by their total surface area. [2]

2.1.6 Formation

Formation is the small-scale basis weight variation in the plane of the paper sheet. Thus the particular densities of fibres, mineral fillers, and chemical additives, they are distributed non-uniformly. Afterwards, measured grammage is always averaged by given area, however particular grammages vary. This fact affects many functional properties of paper, such as tensile strength, bending stiffness, and printing properties. [2]

2.1.7 Fibre orientation

In machine-made papers, there are more fibres aligned in the machine direction than in cross machine direction. Thus the paper is anisotropic material. Fibre orientation index is a number, which gives the anisotropy. This feature influence in-plane mechanical properties and dimensional stability. [2]

2.1.8 Bonds in paper

Fibres are principal structural component of paper. These fibres create bonds and hold each other in the fibre network. Thus one can consider that fibres and bonds determine properties of the final paper. [2]

Bonds have different character, such as:

- Chemical bonds.
- Intermolecular van der Waals bonds.
- Entanglements of polymer chain.
- Inter-fibre bonds.

2.2 Paper properties

Some of the paper properties are stated in following sub-chapters. There were picked those, which are important to consider during experiments in analysis part of master thesis.

2.2.1 Shrinkage

During paper drying, shear stresses are generated in the inter-fibre bonding area. These stresses act on fibres and bonds, what cause shrinkage. Continuously it affects the mechanical properties of paper. It is an issue in drying stage of paper machine, where is the fibre net dried, thus the paper net is stretched during the drying.

2.2.2 Roughness

Roughness is especially significant in printing papers, graphical boards, and many packaging boards. It refers to the uneven surface of paper and board. This property is important for inking and coating. Roughness has three components according to the in-plane resolution: [2]

- Optical roughness – relates to the surface properties of individual pigment particles and pulp fibres.
- Micro roughness – in turn arises primarily from the shapes and positions of fibres and fines in the network structure.
- Macro roughness – is the result of paper formation. [2]

2.2.3 Sheet compressibility

Paper is very compressible in its thickness direction, when the z-directional elastic modulus is Ez = 10-50 MPa. Even a small compressive pressure affects the measurement of thickness and roughness. A common belief is that paper compression occurs in the pores of the network while fibres are essentially incompressible. [2]

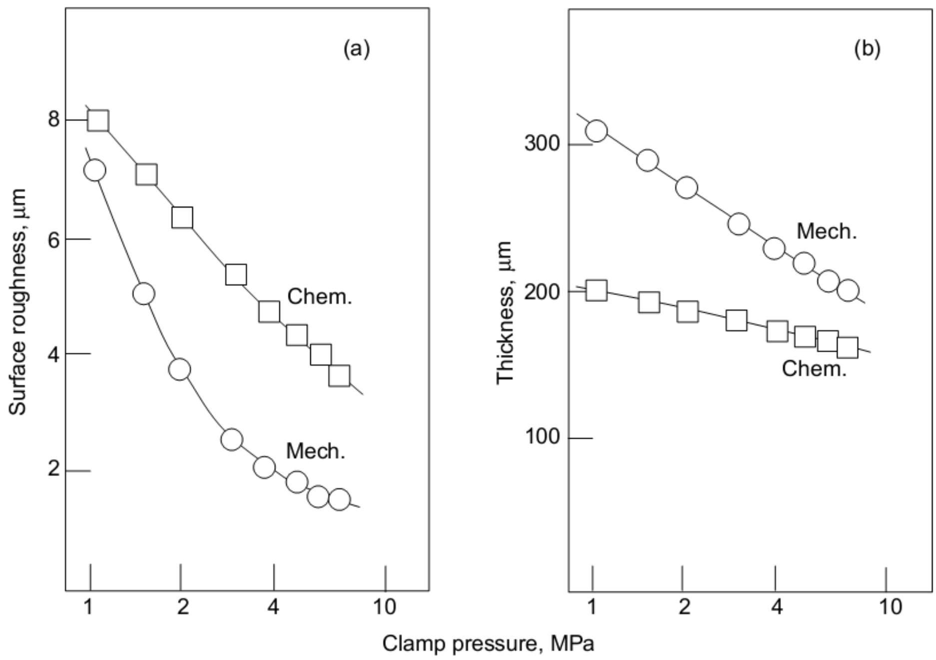

Figure 8. Surface roughness (a) and thickness (b) are depended on logarithmical scale of clamp pressure. [2]

2.2.4 Friction

Friction is a general interfacial property of surfaces in contact. Friction manifests itself as a force that resists the displacement of one surface relative to the other. The friction between two paper surfaces is often more important than the friction of paper against other materials such as metals. The friction coefficients of paper against paper typically vary from 0.25 to 0.70 depending on the paper grade and its surface properties. The coefficient of static or kinetic friction describes the friction of paper. [2]

2.2.5 Bending stiffness of P&B

During the pressing of waste paper, the board is resisting within its bending stiffness. It is a basic quantity in engineering mechanics. Usually it plays important role for good runnability on the paper machine or packaging machine, printing presses, and converting machines. Continuously it rises with high rigidity and strength. Basis weight primarily controls bending stiffness, thus high basis weight would give high bending stiffness. [2]

2.2.6 Comprehensive strength of P&B

In-plane compressive strength is an important property of paperboard. Compressive strength is typically one-third of tensile strength. Compressive strength is by definition the largest compressive force that a piece tolerates without failing. With paper or board, compressive strength is usually given as force per unit width. This is not a material property because it depends on basis weight. [2]

A Table 1 defines compressive calculations within F – the failure force, A – the cross-sectional area, W – the width of the test piece, b – basis weight, and ρ - density.

Property	Symbol	Definition	Units
Compressive failure stress	σ_c	F/A	N/m^2
Compressive strength	s	F/W	N/m
Compression index	P	$\sigma_c/\rho = s/b$	Nm^2/g

Table 1. Compressive calculations. [2]

Comparison of stress-strain in compression with the tension curve (Figure 9):

- Elastic modulus is the same in tension and compression
- Nonlinear region is very short in compression

- Compressive strength is approximately one-third of the tensile strength in MD and one half in CD
- Compressive breaking strain is one-fourth of the tensile breaking strain in MD and one fifth in CD. [2]

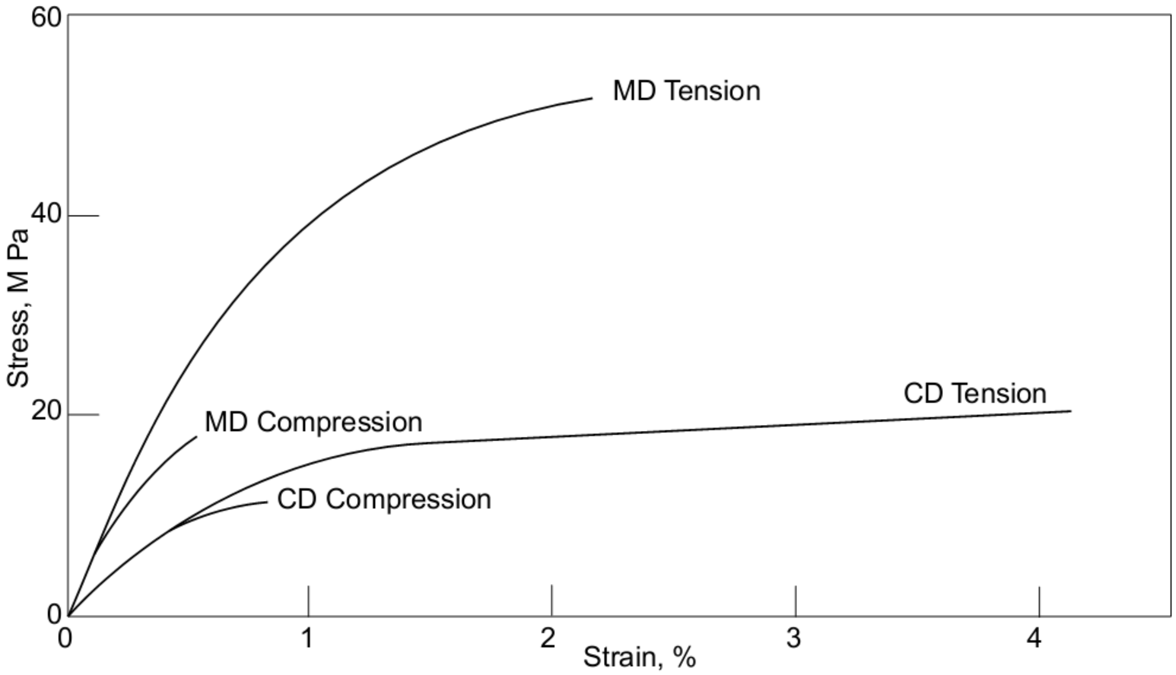

Figure 9. Stress-strain curve of a paperboard in tension and in compression. [2]

2.2.7 OUT-of-plane strength of P&B

Out-of-plane strength measures the ability of paper or board to withstand tensile stress in the thickness direction. Figure 9 shows the stress-strain curve in compression. The board material is deformed within very small pressing force. The curve reaches the constant value of deformation with certain value pressing force. Other words, paper is not possible to compress anymore or just minimally. The behaviour must be very similar to that of any porous material. The principal controlling factor is the distribution of local pore volume. In spite of the higher pore existence of paper stack, the deformation is higher than within single sheet deformation, which is multiplied by number of paper stack sheets. [2]

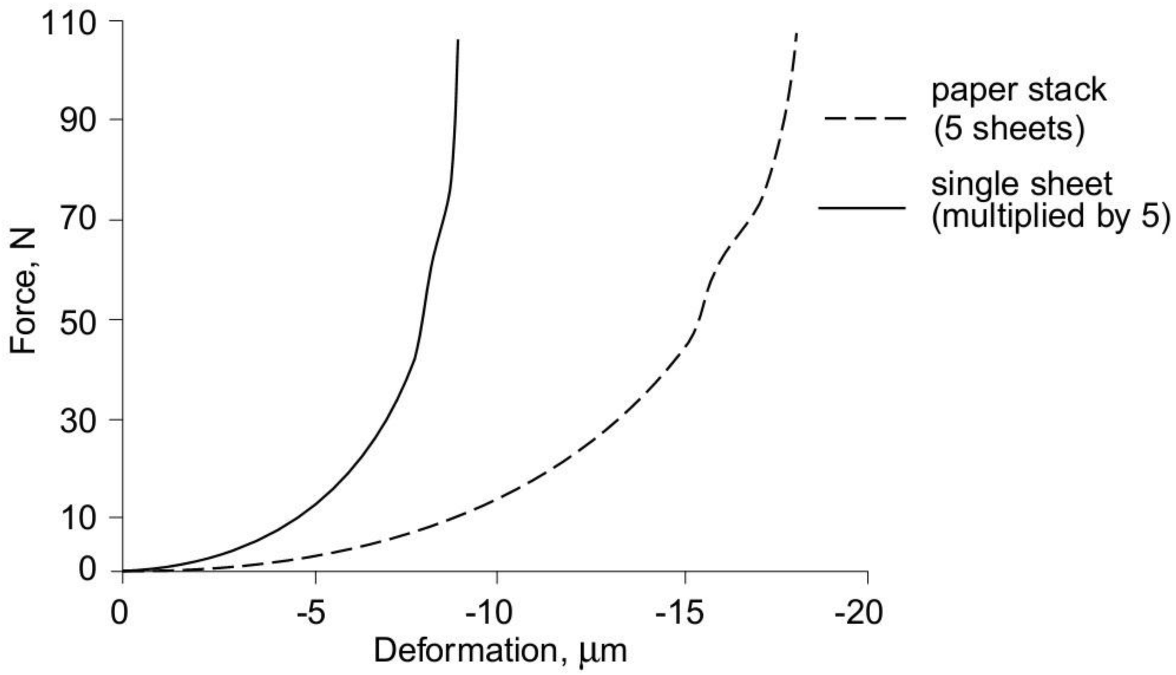

Figure 10. The out-of-plane stress-strain curve of a press-dried paper in compression. [2]

2.3 Moisture content and fibre interaction

Paper fibres conserve some physics properties of wood nature, mainly its sensitive interaction with water. Paper is a hygroscopic material which transforms dimensions and shape whether moisture content changes.

Dry paper shows high stiffness and brittleness, contrariwise the paper with high moisture content is soft and incompact. By rising MC, the elastic modulus and the tensile strength are decreased. Wet fibres swell and slide past one another, thus wet paper is much easier to press, to pull and to disrupt. [2]

2.3.1 Equilibrium state of moisture content

The relative humidity of air gives the amount of water vapour in air relative to the amount in saturation. When the paper is placed under the ambient conditions, the moisture content is reaching equilibrium state with these conditions. During the saturation the paper absorb the moisture of ambient relative humidity. When the paper desorbs the moisture, the drying process is identified. [2]

The moisture content reaches the highest value at the humid and cold conditions. Additionally is necessarily to consider moisture-history and paper's density, which affects sorption capability. [2]

Figure 11 shows the relationship between temperature, relative humidity, and moisture content of softwood pulp. This example can be considered for a paper material as well. [2]

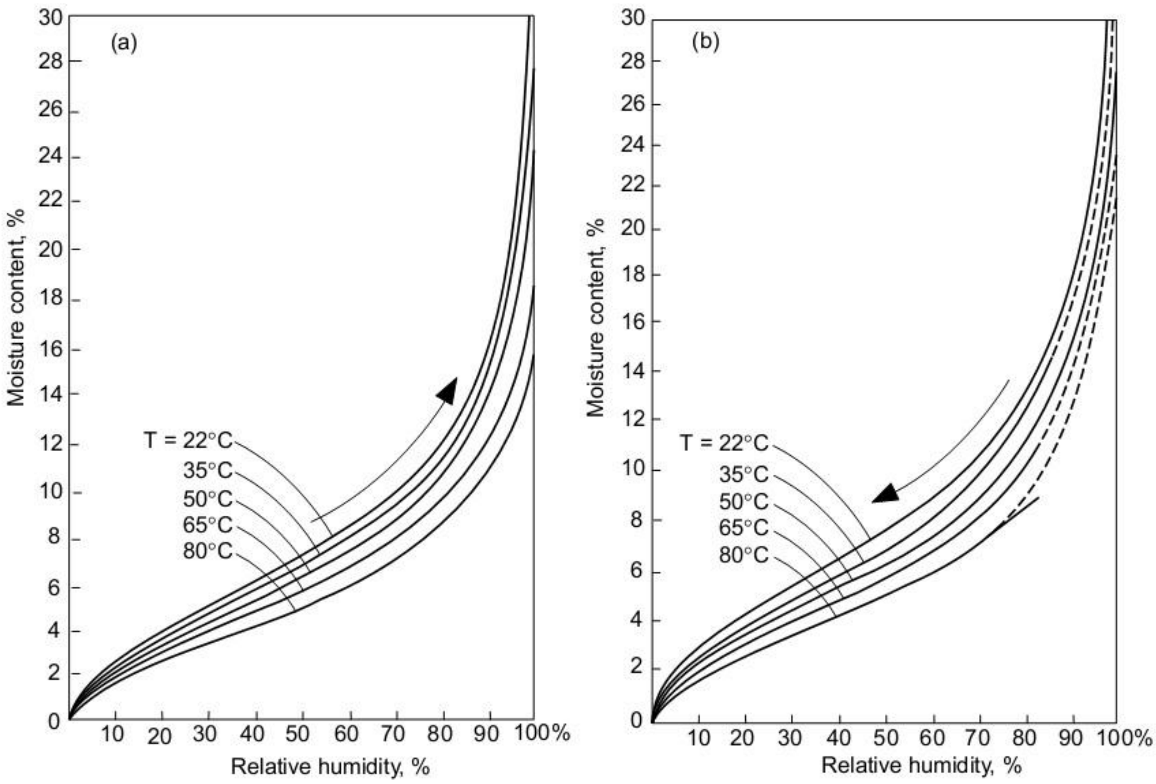

Figure 11. Moisture content vs. relative humidity in a softwood pulp of absorption isotherm (a) and desorption isotherm (b). [2]

2.3.2 Dynamic phenomena

The moisture content of paper can't be change immediately with new ambient conditions, thus MC is change proportionally to the square root of time. Diffusion time is proportional to the basic weight.

Firstly it has to be changed the temperature and RH of sheet boundary layer. Therefore the paper sheet absorbs or desorbs the moisture from ambient RH until the heat balance will be in equilibrium state. For example, cold and dry paper absorbs moisture and oppositely warm and wet paper desorbs the moisture. The heat change is faster, when the air blows to the paper sheet. [2]

2.3.3 Interaction of water with pulp fibres

Papermaking pulp fibres absorb water either as free water or bound water:

- Inter-fibre free water in the pores between fibres.
- Intra-fibre free water in the lumen of fibres.
- Freezing bound water in the pores of fibre wall.
- Non-freezing bound water - chemically bonded to the hydroxylic and carboxylic acid groups in fibres.

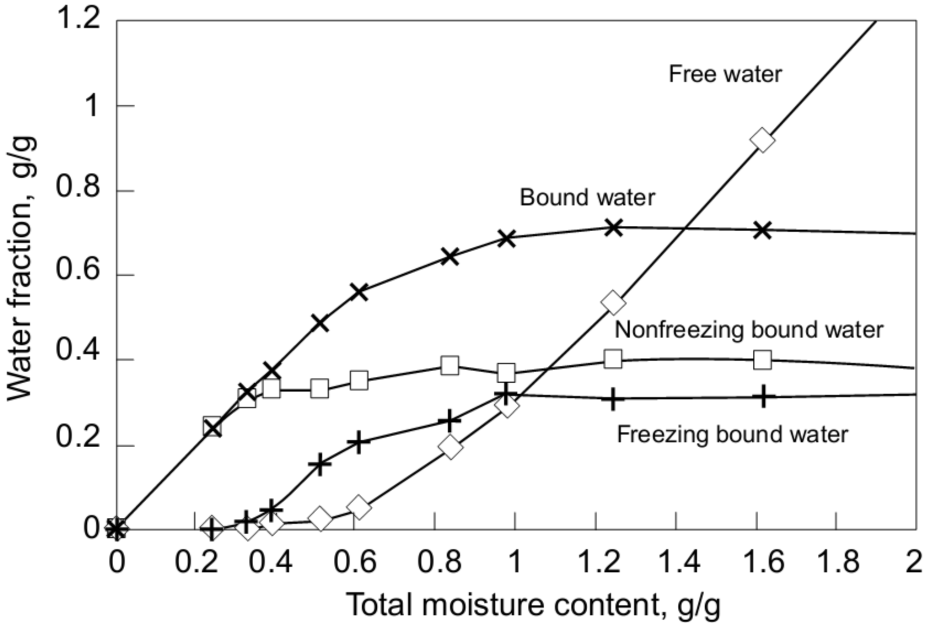

Figure 12. Relative portions of different free and bound water fractions vs. moisture content of the pulp. [2]

3 RECYCLING

Papermaking industry is based on the long and rich history. The first sign comes from 2nd century BC in China. Naturally, humankind has made a huge step forward. Nowadays, the production and consumption are annually counted in hundreds millions tonnes world-wide. It creates a wide spectrum for business, logistic and engineering approach. On another hand, the ecological impact is very strong in spite of wood sources. Thus it is important to look for sustainable manner of paper production.

3.1 Production and recovering overview

Paper and board material is manufactured in whole world. Production quantity depends on raw material sources, know-how sources and consumption. Countries with higher rate of business produce large amount of P&B. This trend is shown in Figure 13, when Europe, Asia and North America cover about 90% of total world production.

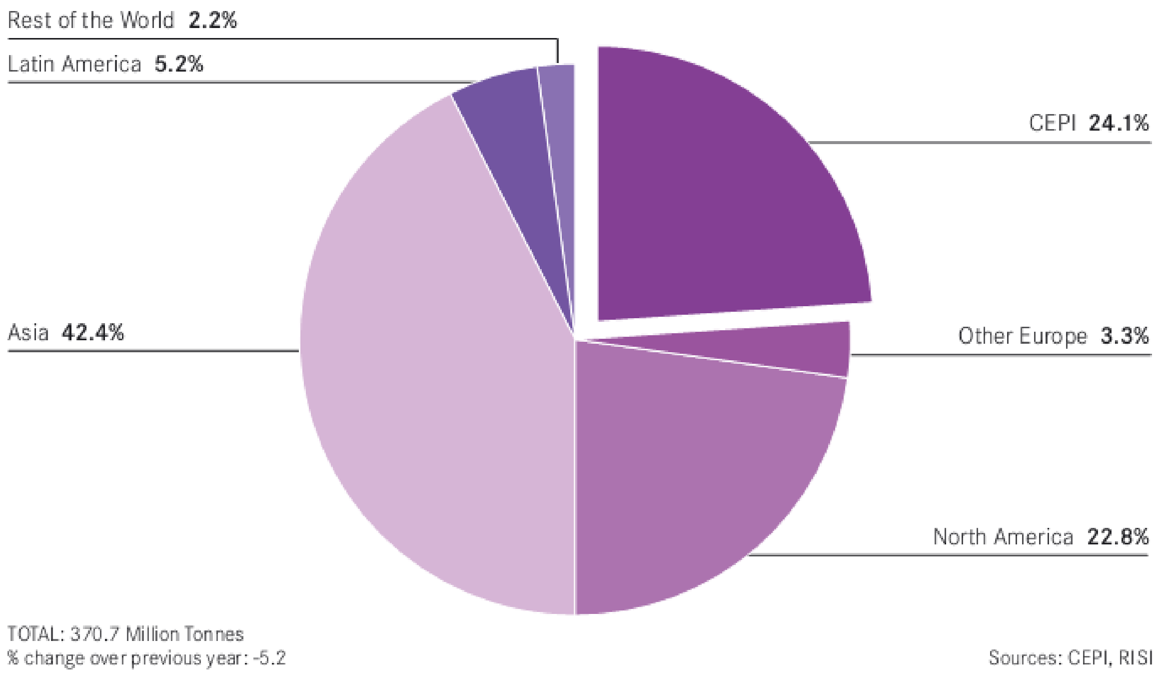

Figure 13. Paper & board production by world region in 2009. [7]

It is important to have a notion about present situation in Europe. As we can notice in Figure 14, CEPI leader of paper and board production is Germany. Secondary producers are Finland, Sweden, Italy and France. Third category is occupied by Spain, Austria and United Kingdom. Czech Republic is somehow lost among the European leaders, because there is not such papermaking tradition and environment. Despite of this fact, there are 22 paper mills of middle and smaller size, which usually buy the pulp and produce the paper matter only.

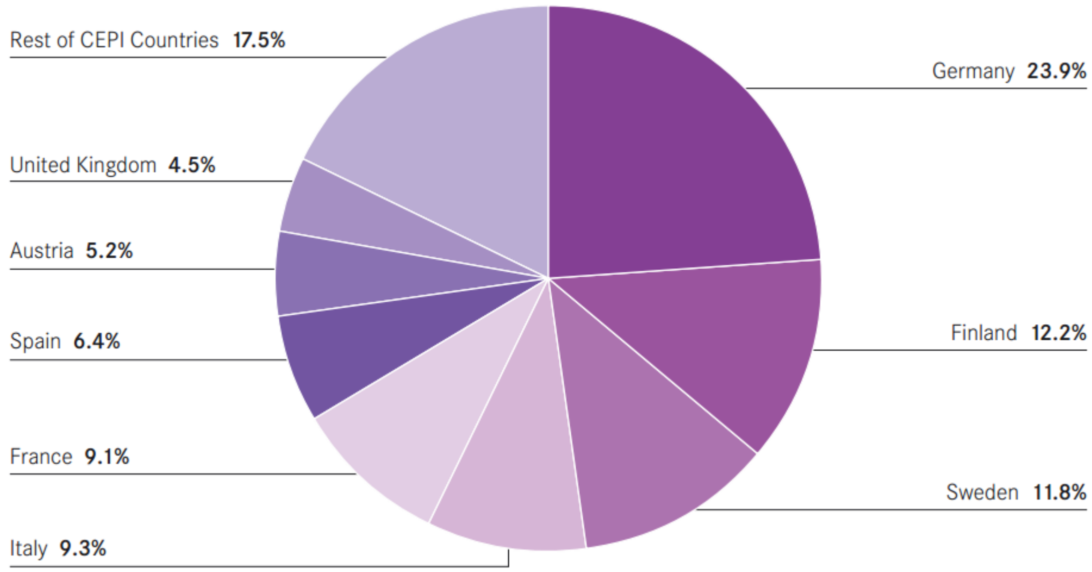

Figure 14. CEPI paper & board production by country in 2010. [7]

Total production and consumption of paper and board is increasing past 10 years. This is noticeable in Figure 15. Because of financial crisis in 2009, production and consumption decreases very sharply. In spite of this fact, the trend is nowadays still growing and it is awaited a continual trend in this area.

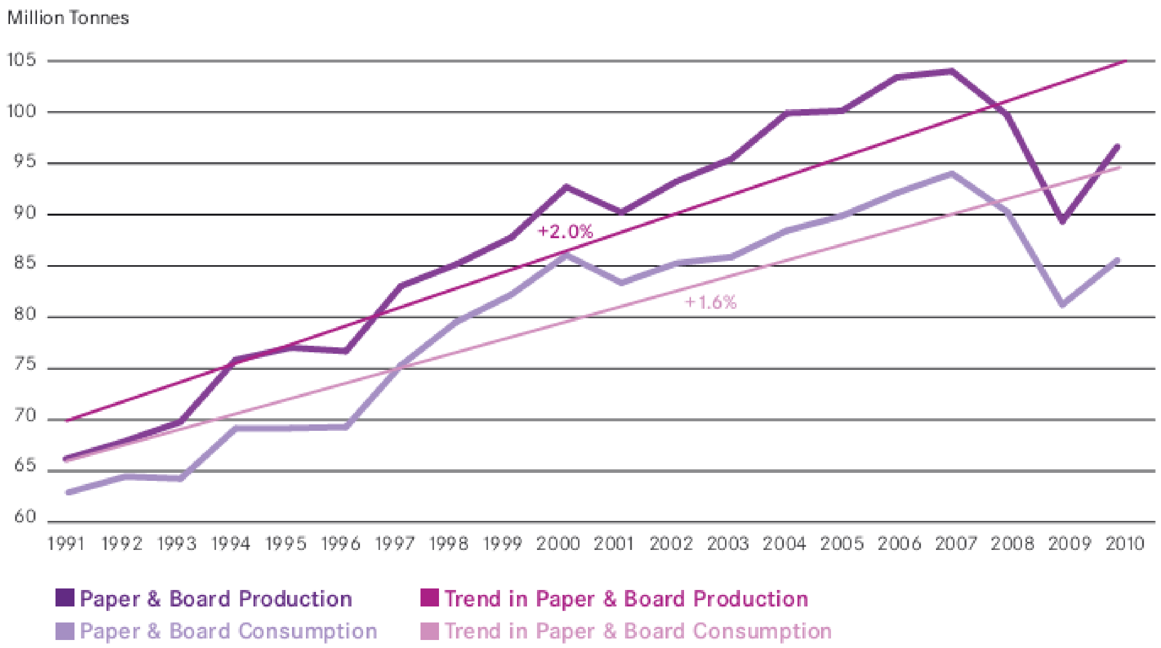

Figure 15. CEPI Paper & board production and consumption 1991–2010. [7]

Raw material consumption has been changed past 10 years in Europe. Since the wood-pulp uses is decreased, the recycled pulp from recovered paper is increased. Figure 16 show this increasing trend. Afterwards one can expect higher ration of recovered paper use in future.

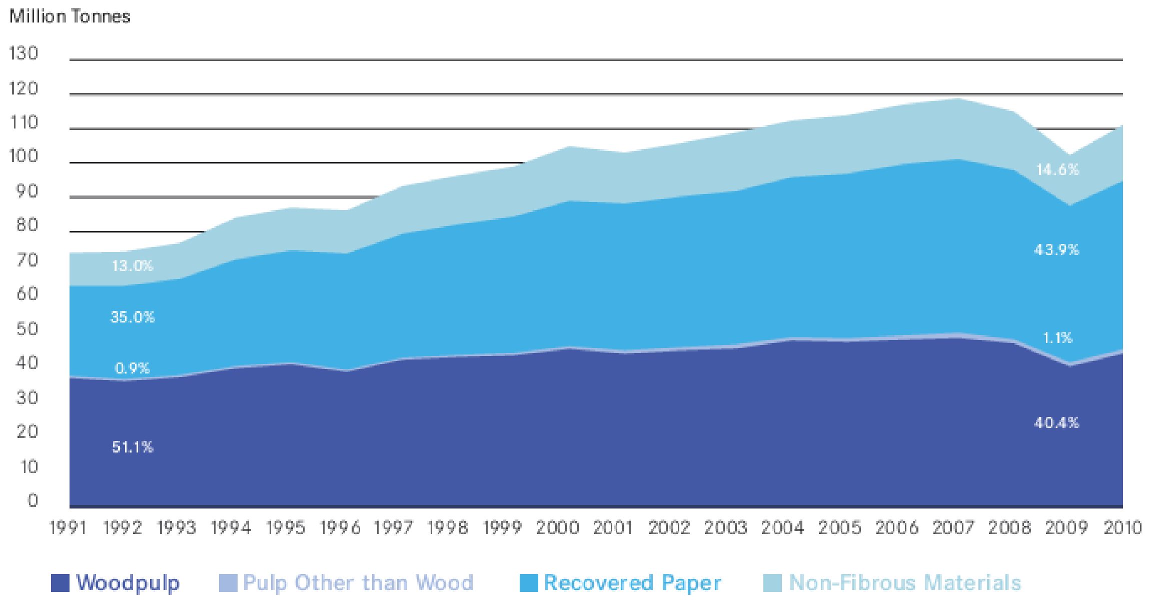

Figure 16. CEPI raw materials consumption 1991-2010. [7]

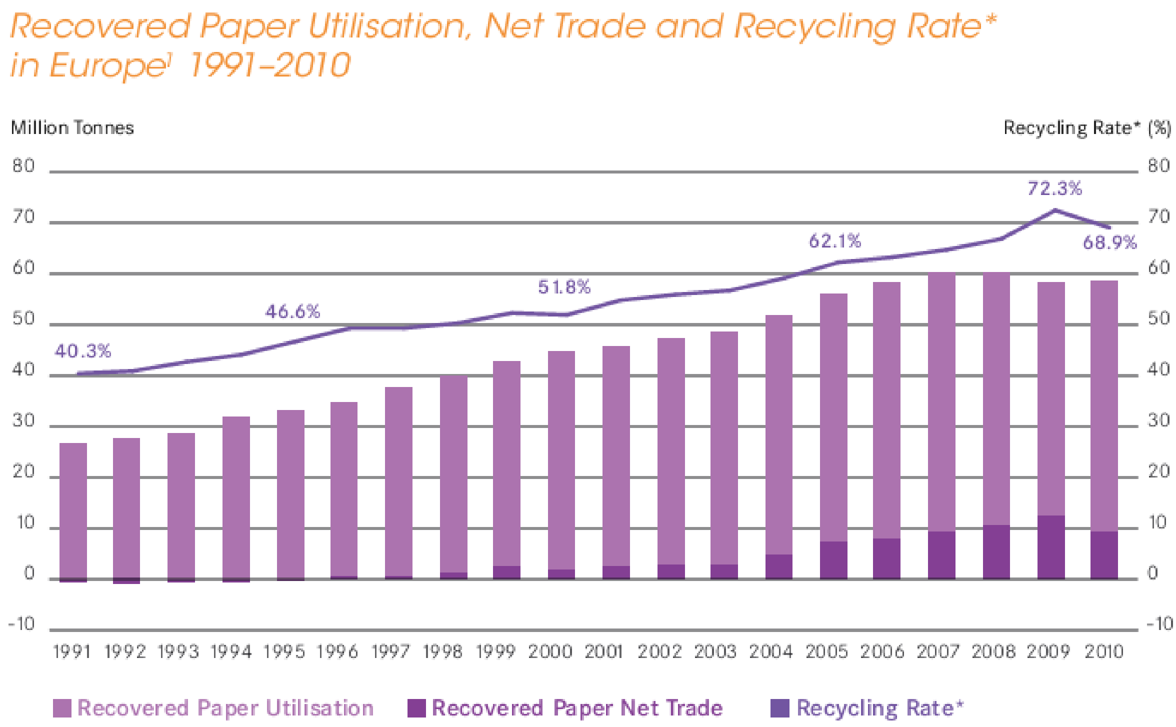

Figure 17. Recovered paper utilization, net trade and recycling rate in Europe 1991–2010. [7]

By Figure 17, recovered paper utilization in CEPI countries is in high level among all world regions. About 60 million tons of paper was used in paper mills for recycle. The significant fraction is recovered paper net trade, what makes about 9.3% of total P&B production. Almost entire amount of this material is exported to the China. Summation of these two values represents the total recovered paper collected in CEPI. Comparison within total P&B production, the recycling rate is 68.9%. Thus, app. 6.9 tons of produced paper in Europe is collected and used for another application. The trend past 10 years is growing, so the higher recycling rate is expected in following years.

3.2 Recovered paper prices and trends

Prices of recovered paper vary every day and differ in every country. For instance in October 2010, the metric ton of recovered paper cost in Germany 115Eur. In the same time, French mills were buying it for 80 Eur per ton. After 6 months in April 2011, in Germany RP costs 160 Eur per ton and in France 130Eur per ton. During the crisis in December 2008, the price of RP was about 30 Eur per ton in Germany and 10 Eur in France. Based on these facts, the financial value of RP depends on the present situation in market. Thu biggest importer of RP is China, which paid 180Eur per metric ton in October 2010. [7]

3.3 Policy in EU

The EU member states must establish systems for take-back, collection, and utilization of used products as secondary raw material. All parties involved in the production, converting, import, and distribution of packaging and packaged products must become more aware of the degree to which packaging becomes waste. They must also take responsibility for this waste in accordance with the "polluter pays" principle. Final consumers play a decisive part in the prevention and use of packaging and packaging waste. They therefore require education. The efficient separation of waste at its source such as in private households has major importance for a high recycling level. [1]

II. ANALYSIS

4 INTRODUCTION THE ISSUE IN EUROPAC KRAFT VIANA

The master thesis was performed in a paper mill in Portugal. For years, it was a problem to determinate the moisture content of recovered paper bales. Sometimes it appeared to be suspicious that recovered paper contained the moisture out of an allowed range, which is 8% - 12% [6]. Company receive approximately 13 000 tons of recovered paper monthly [5]. Apparently, it is important to determinate exact moisture content and to pay only for true fibre and not for water.

4.1 Background of recovered paper in the Europac Kraft Viana

Europac Kraft Viana cooperates with 25 – 30 suppliers, which collect – press – store – deliver the recovered paper in a bale form to the mill. Bales are unloaded from the lorry and stored in the recovered fibre yard. This is shown in Figure 18.

Bales have different mass ratio of rejects and recycled fibre. Thus, there exist many paper grades. European List of Standard Grades of Recovered Paper and Board (ELSGRPB) describe these bale grades [6]. In our case, there are only 3 bale grades, which enter the mill in Viana do Castelo:

- 1.04 – Supermarket corrugated paper and board - used paper and board packaging contained a minimum of 70% of corrugated board, the rest being solid board and wrapping papers.
- 1.05 – Old corrugated containers - used boxes and sheets of corrugated board of various qualities.
- 4.03 – Used corrugated kraft - used boxes of corrugated board, with liners of kraft or testliners but having at least one liner made of kraft.

Recovered paper in Europac Kraft Viana is used as:

a) A raw material for manufacturing of new kraft (sustainability profit).
b) A biomass for energy production (financial profit).

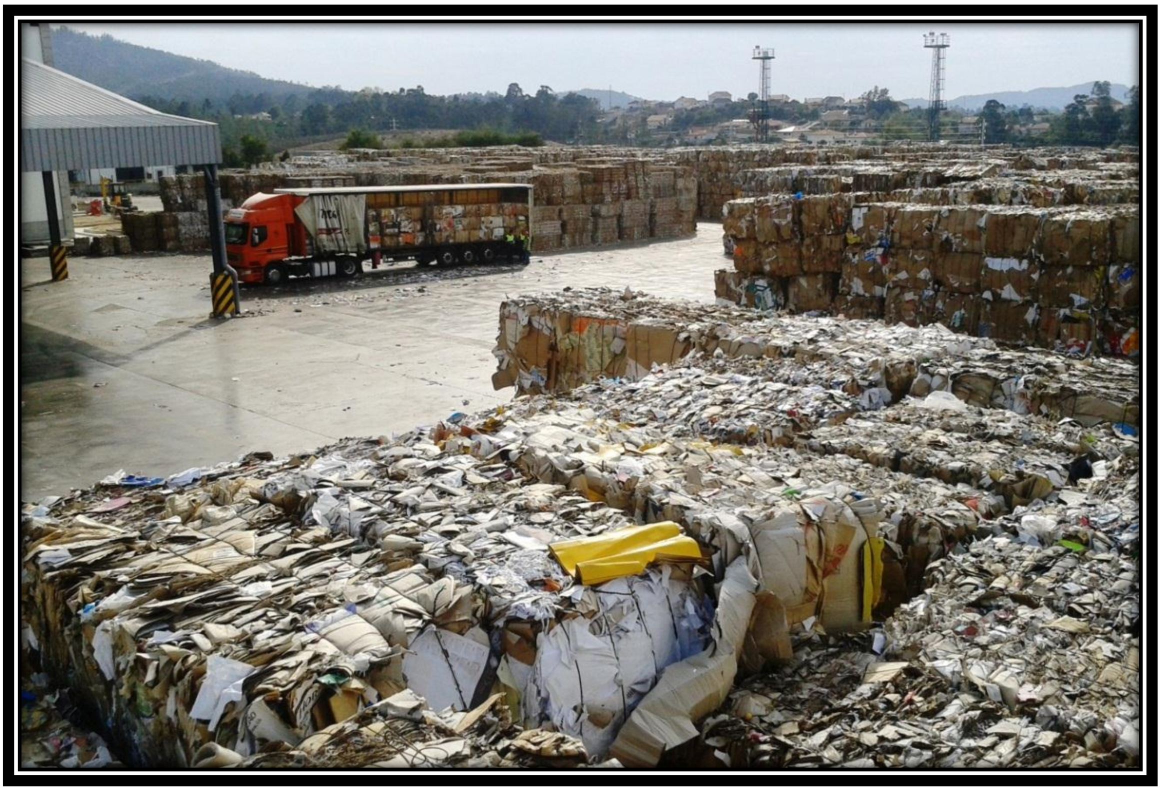

Figure 18. Recovered paper yard in Europac Kraft Viana.

Figure 19. Difference between the grade 1.05 (on the top) and the grade 4.03 (on the bottom).

Figure 20. Waste paper bale (grade 4.03).

Figure 21. Waste paper bale (1.05).

The moisture content of the bales is determined by sampling paper from 3 selected bales for each lorry load. At the end of the day, these samples are sent to the laboratory to verify the moisture content.

Each lorry has a reference number which helps to find information of the dried paper mass. At the same time, it can be useful with to find a location of the bales in the yard.

The bales are usually stored in the yard for 3-4 weeks. The moisture content can change during that period in contrast with the dried fibre mass. After, the bales are transported to the recycle fibre mill for the division of the rejects and pure recycled fibre. Then, the pure recycled fibre is supplied to the paper machine or for the production of energy.

There is a flow meter and a consistency meter between the consistency tower and paper machine. It is possible to calculate the recycled fibre mass based on the values of these two variables (this estimate is known as the TAC estimate). Also, two devices are inside of the paper machine, where we can estimate the mass flows (this estimate is known as the paper machine estimate). In other words, we have two estimates of the mass of recycled fibre.

4.2 Diverse values of moisture content

The measured data are sampled and analysed by the laboratory (from now on, will be known as the oven-dried technique). They are stored in control software called SAP. Subsequently, data via OD-SAP are compared with data via paper machine and via TAC estimates.

It is noticeable, that the values of the moisture content are different. The moisture content obtained by the three techniques is comparable during the months with low precipitations. The biggest differences occur in months with higher precipitations. In Figure 22, it can be seen the behaviour of the three moisture figures in a 16 months period.

The values via paper machine and values via TAC are delayed approximately 1 month in comparison to the values via OD-SAP and precipitations. Therefore, it is clarified that the period is approximately one month between the sampling and inputting of the bales to the recycled fibre mill.

For instance, on January 2010, the average moisture content, estimated via paper machine, was 23.4%. It meant that the 1000 kg of paper mass contained 234kg of water instead of 100 kg. Finally, company paid for 134kg of water instead of paper fibre.

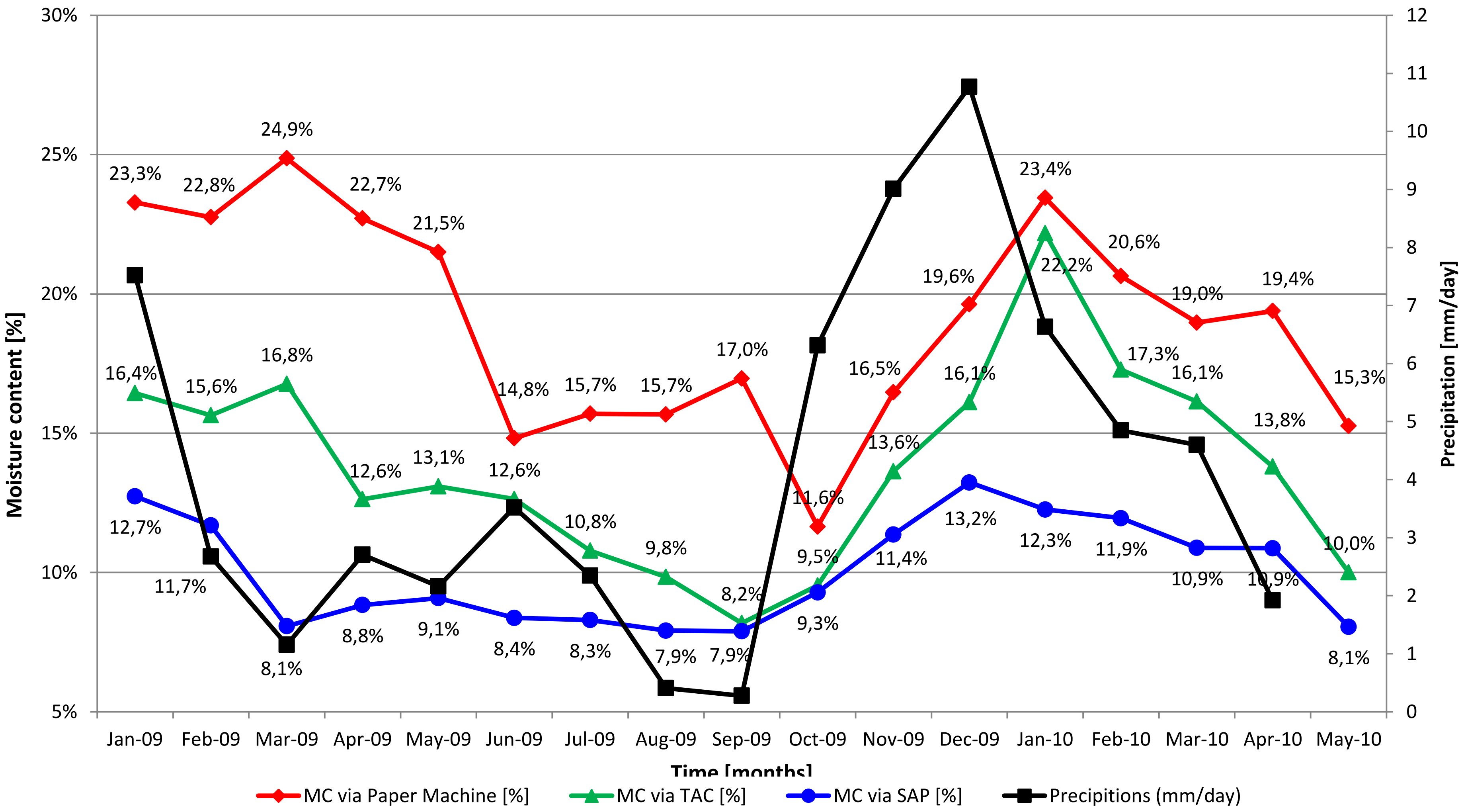

Figure 22. Annual estimations of moisture content of waste paper bales.

5 OVEN-DRIED TECHNIQUE

Actual oven-dried technique is based on taking samples randomly from the bale. When the bales are unloaded from the lorry, several samples are taken from 1 or 2 bales. The total weight of the taken samples is usually around 200 – 300 grams. The samples isolated in plastics bags are delivered to the laboratory, where the moisture content is determined by drying in the oven. The mass of the water is described as the difference between total samples weight before and after drying. By this the moisture content is determined and correlated to the sampled lorry load.

Every lorry has a reference number, which is written on the plastic bag. Therefore the estimated moisture content is corresponded to every lorry load, in each position in the yard.

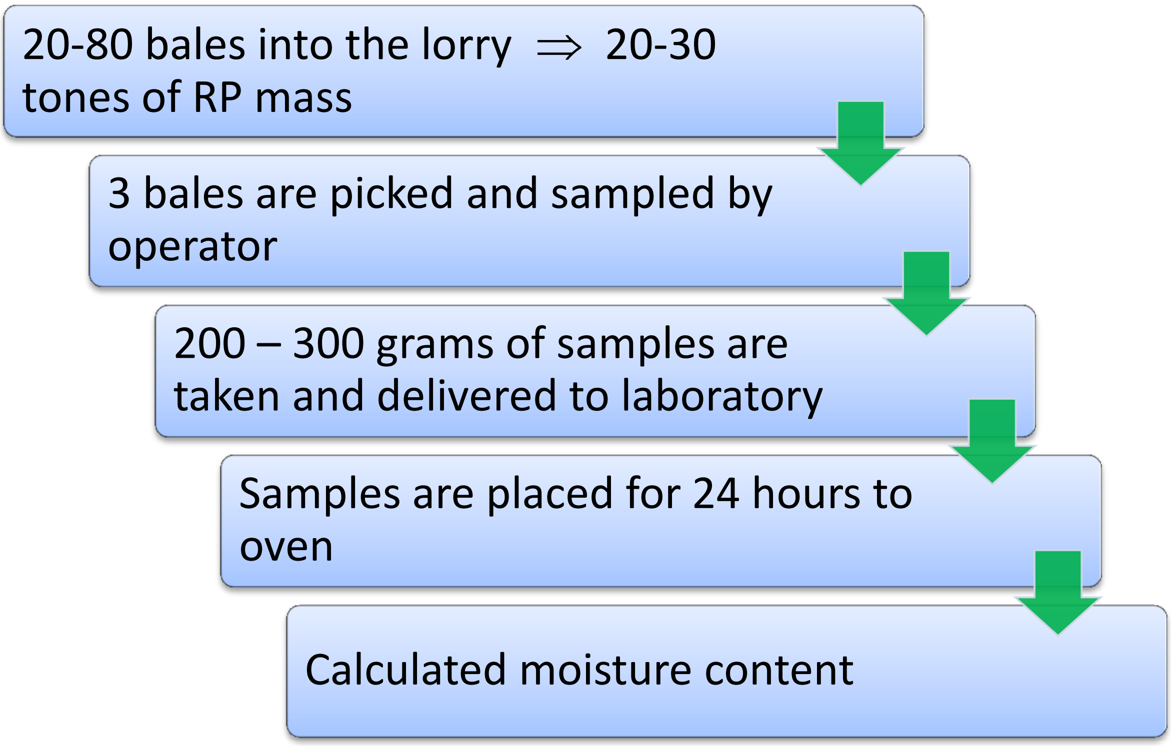

Figure 23. Approach of the oven-dried technique.

The results of this technique show different values comparing to the estimated values from the process. Thus experiments were designed on the paper yard to describe moisture content behaviour and to find the weakness of this technique.

5.1 Paper bale moisture profile

The recovered paper is pressed into the bales. Each bale has prism shape with dimensions approximately 1m x 1m x 2m. Paper mass is pressed randomly by such machine, as shows Figure 24.

The waste paper is not usually kept in good warehouse conditions. Mostly the recovered paper is stored out of the shelter. Thus a rainy weather and humid conditions have a huge impact on the waste paper moisture content before and after pressing.

Figure 24. Horizontal waste paper baling press – Techgene Machinery Co., Ltd.

5.1.1 The moisture profile technique description

The waste paper is pressed very randomly. The moisture could reach various values in different locations. Hence it was developed the moisture profile technique. This technique will help us to describe a moisture profile by section of the bale. There are four sections along the bale (Figure 25) and each section is allocated as Figure 26 shows.

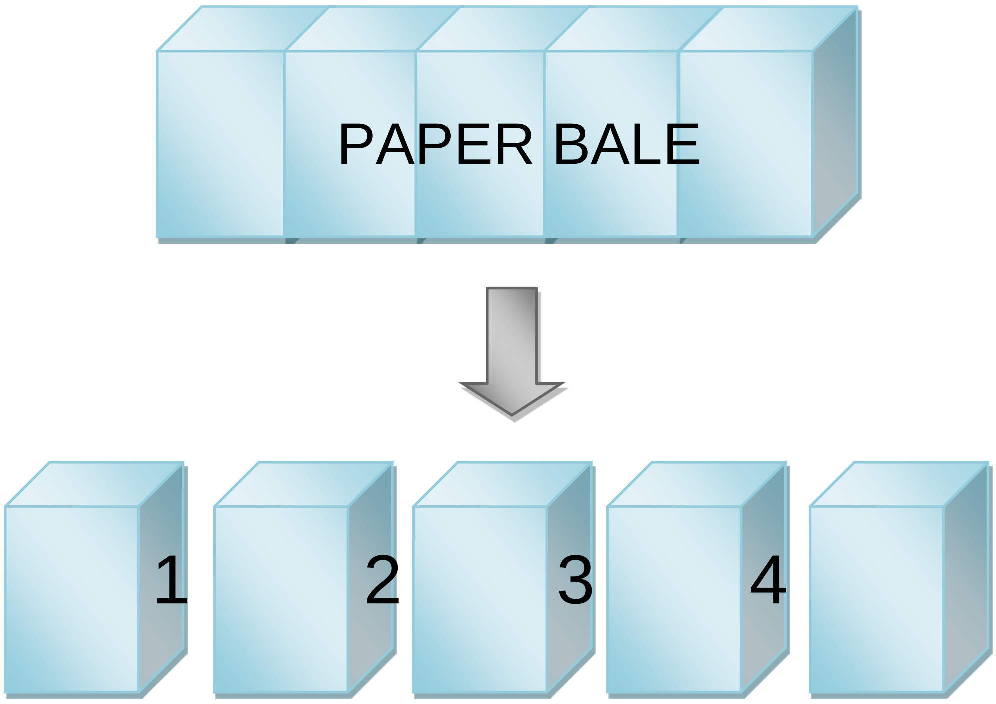

Figure 25. Paper bale is divided by 4 sections.

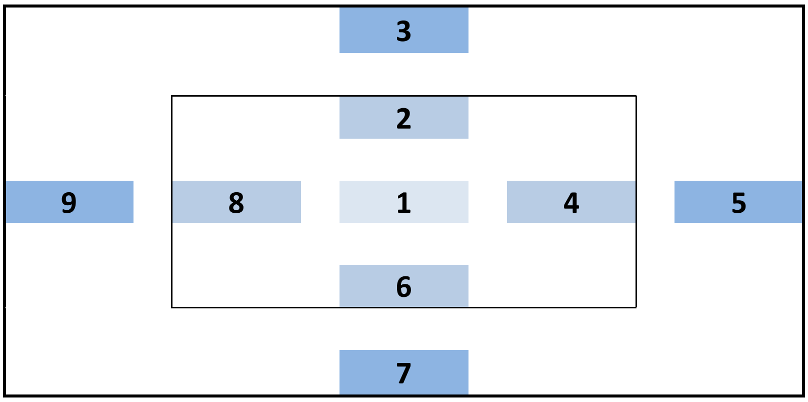

Figure 26. Section allocation.

After bursting the bale, each sample (approximately 20 - 40g) was taken from its location. As quick as possible, the sample has to be isolated in the plastic bag, as well as marked and delivered to the laboratory. The sample's moisture content should remain unchanged. When each sample is weighted, dried for 24 hours and weighted again, the moisture content MC is calculated within equation

$$MC = \frac{m_T - m_{OD}}{m_T} \cdot 100 = \frac{m_W}{m_T} \cdot 100 \quad [\%] \qquad (1)$$

where m_T is total mass weight in grams before drying, m_{OD} is samples mass in grams after drying, which is also so called oven-dried mass. Difference of these two measured masses provides water mass m_W in grams.

5.1.2 The moisture profile technique results

Furthermore five bales were checked by me and five bales by Eng. João Inácio. Our results are very comparable. The following results of only two typical examples will be examined further.

Figure 27. Moisture profile of “wet” bale (1.05), ref. No. 96105.

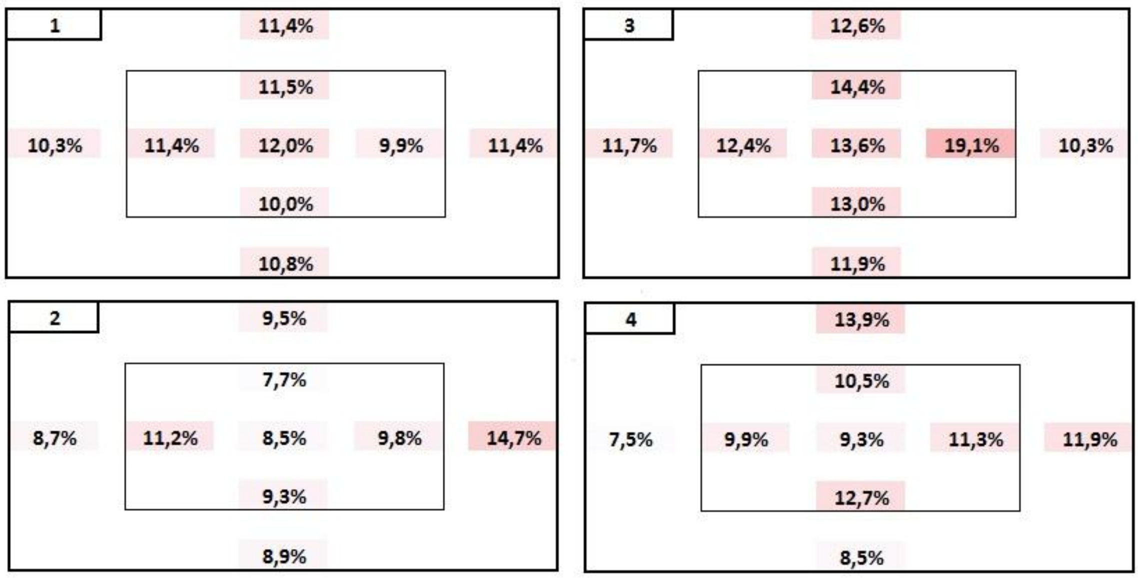

Figure 28. Moisture profile of “dry” bale (1.05), ref. No. 101124.

There are two various moisture profiles of “wet” bale and a “dry” bale. Same positions in different frames have very dissimilar moisture content. It is noticeable, that the waste paper bale is strongly non-uniform. Each position has a highly different moisture content inside of the bale (difference is approximately 5-10%). Moreover, it is not possible to predict, which position corresponds to the true moisture content of the bales. In spite of non-uniformity, the dry bale shows slighter moisture differences between locations comparing to the wet bale.

5.2 Waste paper drying curve

The waste paper was pressed in the bales which were wrapped by the metal wires. Temperature and moisture were somehow preserved inside of each bale. After severing the wires, the bale was burst. Consequently, the conditions inside of the bale were changed. The inner temperature and the moisture content were equilibrating to the ambient. The period of the time between bursting and sampling of the bale was usually delayed about 5-10 minutes. Therefore, an error can occurred between the real moisture content of each bale and the moisture content of each sample. For that reason, the waste paper drying curves were created and they can be described as moisture content changes depending on the time.

5.2.1 Drying approach

The mayor aim was to focus on keeping same drying conditions as the sampled bale is affected usually. Hence, the waste paper drying sample was dried and weighted on the recovered paper yard. There are several atmospheric exposures, which influenced the drying on a large scale such as temperature, ambient humidity, wind speed and atmospheric pressure. Due to the fact, that wind speed was not measurable, the results were uncertain. Nevertheless, these measured data give a trend of the drying.

The waste paper sample was weighted every two minutes and finally dried in the oven. Using the (1) the particulate values of moisture content were given.

Figure 29. Dried and weighted sample under ambient conditions.

It was very important to work quickly. Also, the sample had to be immediately taken out of bursting bale. Every sample had a plane form with dimensions approximately 200 x 200 mm (Figure 29) and the thickness of 0.1 – 0.5 mm.

5.2.2 Drying curve construction

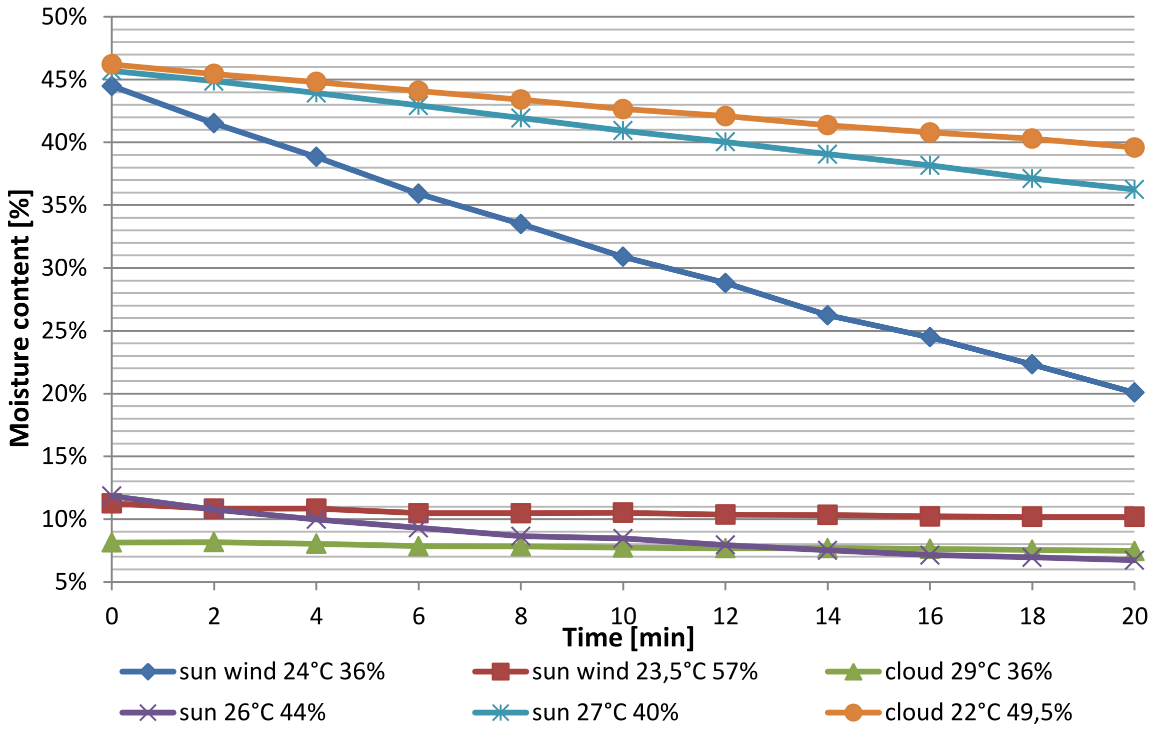

Figure 30. Drying curves of waste paper sample.

Figure 30 shows results of these measurements. There are trends of three “wet” samples and three “dry” samples. The wet samples were losing its moisture content much faster than the dry samples. The wet samples lost 3-14 % of the humidity depended on conditions and sample quality for first ten minutes. It signified a big error. In contrast, the dry samples did not lose that much MC, only approximately 1-3% during first ten minutes.

In conclusion, the sampling of OD technique had to be accomplished as quickly as possible, mainly if the bale seemed to have high moisture content.

5.3 Deficiencies of oven-dried technique

The annual results of oven-dried technique (Figure 22) showed acceptable results (MC=10% ±2%). These results were highly approximated and they did not correspond to the real values. During the observation of this technique and the execution of stated measurements, the following facts were described:

1) Non-uniform character – when the bales contain various quality paperboards, each supplier stores and press the bales under different conditions. Therefore it is impos-

sible to predict the position inside of the bale, which does correspond to the real moisture content of the bale, neither the whole load of the lorry.

2) Sampled pieces are not corresponding with the large delivered mass – the single load of the lorry is huge. One of them weights about 20-30 tonnes of the waste paper mass. Sample mass is usually 0.2 - 0.3kg. It represents only 0.001% of total lorry load, which is moreover completely non-uniform.
3) Delay of paper yard operative – the period of the time between bursting and sampling is usually 5-10 minutes. In specific cases, the real MC of the sample can be changed. It depends on the ambient conditions and the time. This influence an estimated moisture content of sample, which does not correspond with the real moisture content anymore.

5.3.1 Wet bales vs. dry bales

Different facts of "wet" and "dry" bales were observed during the previous measurements. After several weeks of work, it was possible to recognize these two different types of bales just with simple look or touch. The dry bales were relatively in allowed range of moisture content by norm EN 633. A determination of these bales is sufficiently accurate by oven-dried technique. On the contrary, a real moisture content of wet bales was very difficult to describe. Figure 31 shows the comparison of dry bale and wet bale.

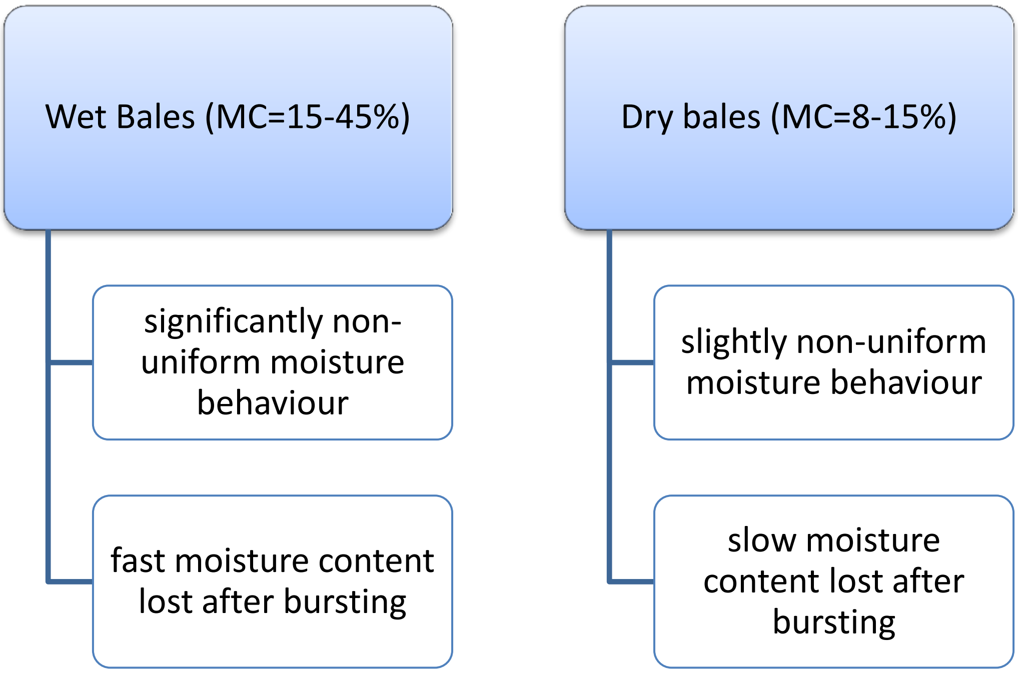

Figure 31. Wet bales vs. dry bales.

6 MOISTURE METER TECHNIQUE

In the previous chapter a closer look was taken over the oven-dried technique as well as properties of the real bale. The previous experiments demonstrated that actual OD technique provided values with deficiencies.

Europac Kraft Viana owns a moisture meter in the warehouse. It is not used because the MM validity has not been proved yet. Thus, it was necessarily to create an approach and to prove or disprove validity of measured data. This equipment describes the moisture content of the bales and it works on dielectrical characteristics of the paper.

6.1 Moisture meter AP 500-M

The AP 500-M is a battery and mobile operated gadget. This electronic hand held measuring instrument for non-destructive determination of moisture content in bales up to a measuring depth of maximum 500 mm.

Figure 32. Moisture meter AP500 – M from EMCO.

6.1.1 Principle of AP 500 – M

The instrument works according the dielectric measuring principles. Thus, there is a penetration of an electric field into the material. Due to the polarity of water and the high dielectric constant of water in comparison to other materials (water has a dielectric constant of 83, paper and natural fibres have the dielectric constant of approx. 2), the capacity of the measuring field is determined of free water molecules. The measuring signal must be calibrated. It depends on the kind of material, the density and the weight.

The measuring value is the dielectric constant (DC) which increased with higher water content in paper. Also it depends on the content of fillers and density of grinded fibres.

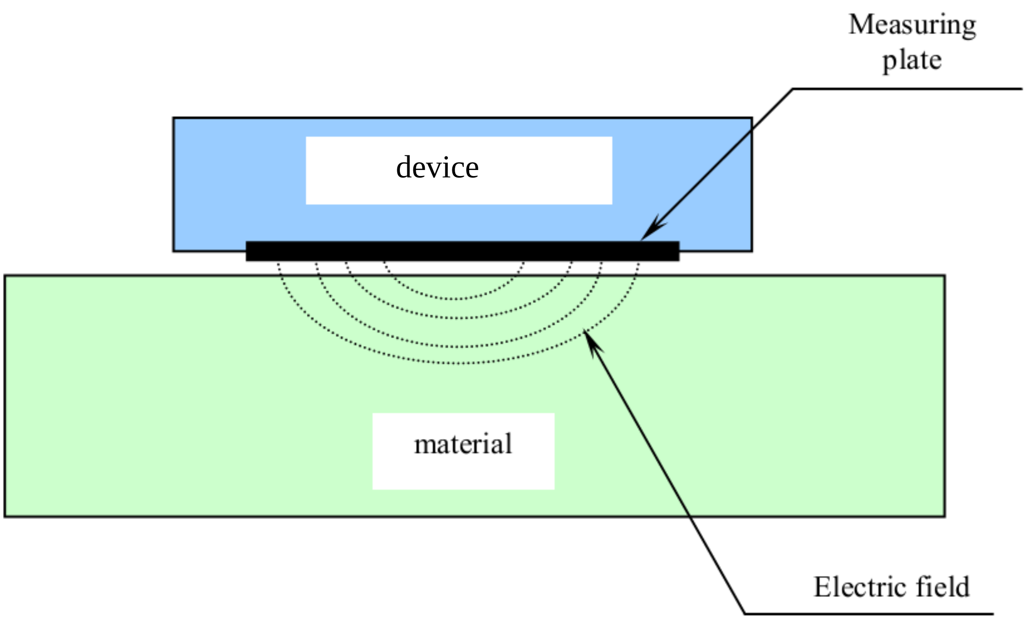

Figure 33. Dielectric principle of AP500 – M.

6.2 Designed approach

The aim of the experiment was to prove the reliability of measured values by this equipment. Consequently, the value of the sophisticated oven-dried technique was determined. Over more, the third value of SAP system was integrated as well. Finally, the following values were compared:

1) Moisture meter value – it was an average value of 21 measurements by the single bale. Each check covered approximately 20.8 dm^3 (8.42kg) of the paper mass (PI).
2) Sophisticated oven-dried value – it was an average value of seven oven-dried samples. Approximately 300 – 400 grams of samples were taken from each frame. According to the previous chapter, the sampling was performed as quickly as possible and very carefully. The aim was carried on precise sampling.
3) Oven-dried value (SAP) – the value was taken from SAP system. It was possible to expect high deficiencies. The checked mass was about 0.35kg.

The non-uniformity of the bales were taken into account during the measurements. Fourteen bales were checked from various loads. The checked waste paper quality was 1.05.

	MM technique	Sophisticated OD technique	OD technique (SAP)
Checked mass per bale	~ 174.2 kg	~ 2.5 kg	~ 0.35 kg
Checking time	15 minutes	24 hours	24 hours
Bale bursting	NO	YES	YES
Type of checked mass	paper + rejects	paper	paper

Table 2. The facts of compared values.

6.3 Description of the moisture meter technique

Every bale was weighted and measured, thus it was possible to calculate a bale density ρ_B by using

$$\rho_B = \frac{m_B}{V_B} = \frac{m_W + m_{OD} + m_R}{a \cdot b \cdot l} \qquad \left[\frac{kg}{m^3}\right] \tag{2}$$

Where m_B is the bale total weight in kilograms, V_B is the bale volume in pressed form. The bale weight consist of the particular masses of water, oven-dried paper, and residues, which are marked as m_w, m_{OD}, and m_R. Other variables a, b, and l are width, height, and length of the bale.

After severing metal wires, the bale still kept the cuboid shape. The bale was divided into the 7 frames by marker (Figure 34). Each frame was checked three times by MM as Figure 35 shows. Finally, the average value of each frame has to be calculated the same as the average value of the whole bale. The total average value represents the moisture content of the frame via Moisture meter. Subsequently, the moisture content via MM will be compared to the other two techniques.

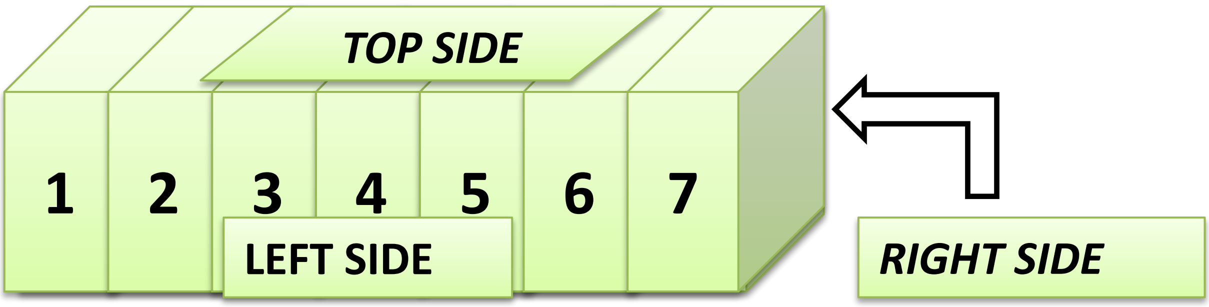

Figure 34. Divisions of the bale.

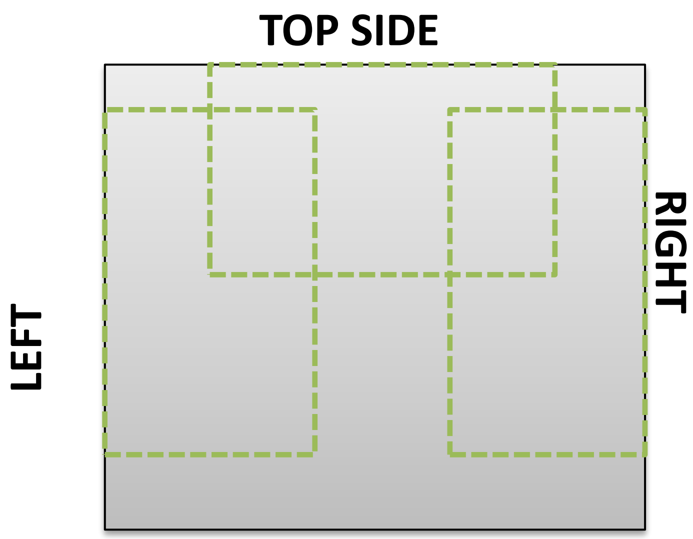

Figure 35. A single frame and measured area via moisture meter.

6.4 The moisture content along the bale

Furthermore, 14 measurements were performed in total. Their results were very similar therefore, only three of them were described because they became the most representative ones. Figure 36, Figure 37, and Figure 38 show the moisture content along the bales. There are drawn two curves. These curves represent MM values and sOD values. Their trends are very similar, but values sometimes differ from each other due to the error in the moisture meter. The waste paper bale grade 1.05 contains these rejects. This apparatus works on dielectric principle, thus it is very sensitive of metal rejects.

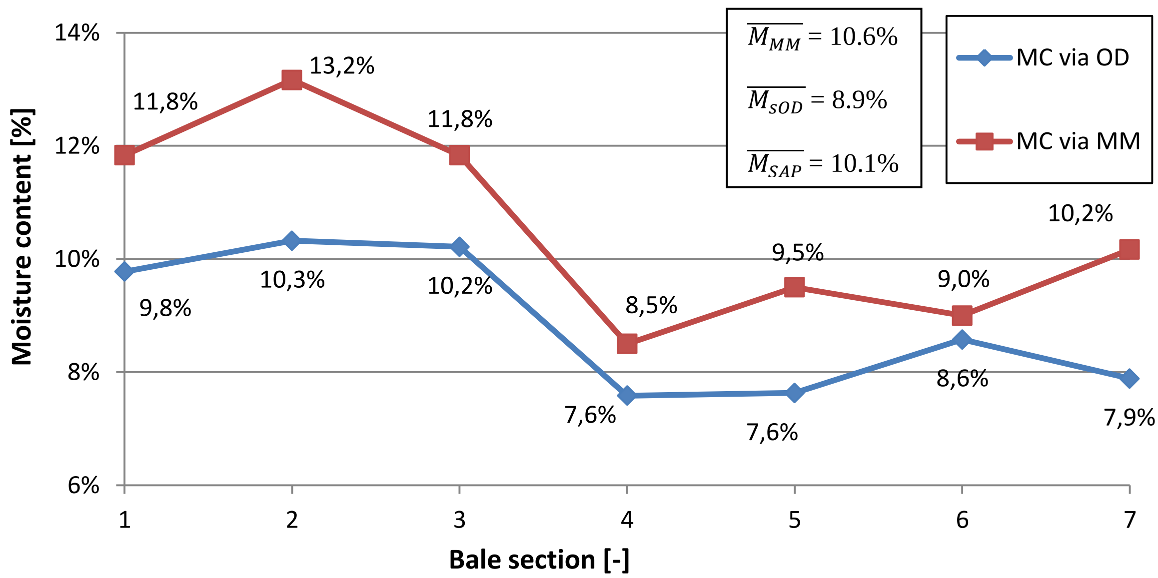

Figure 36. The moisture content along the bale 1.05 – 105446.

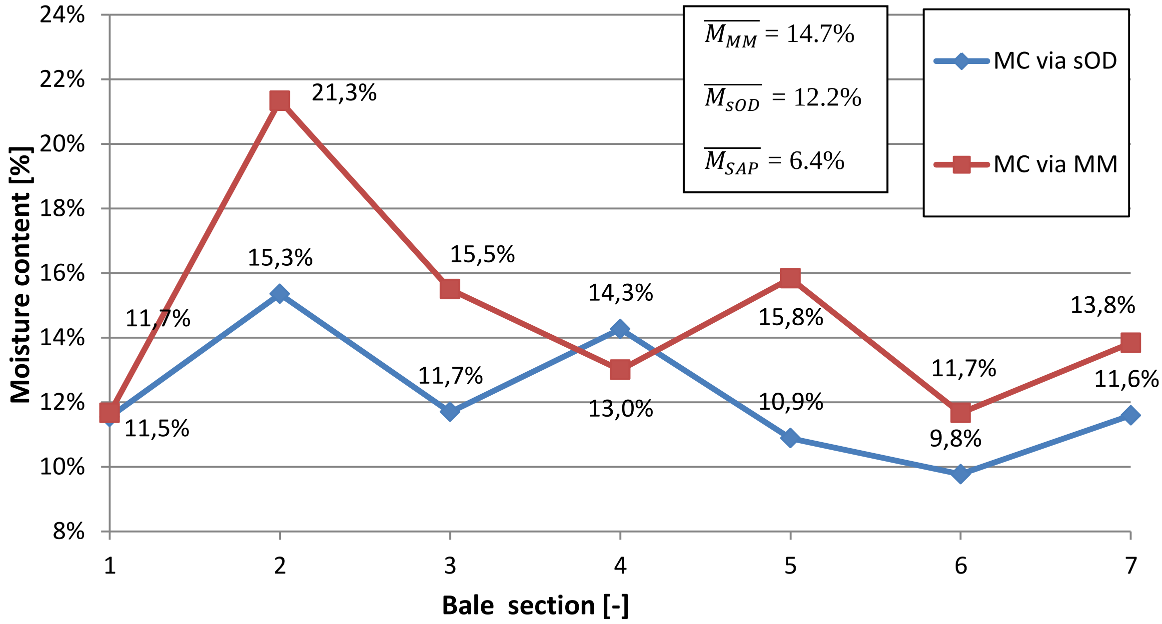

Figure 37. The moisture content along the bale 1.05 – 105335.

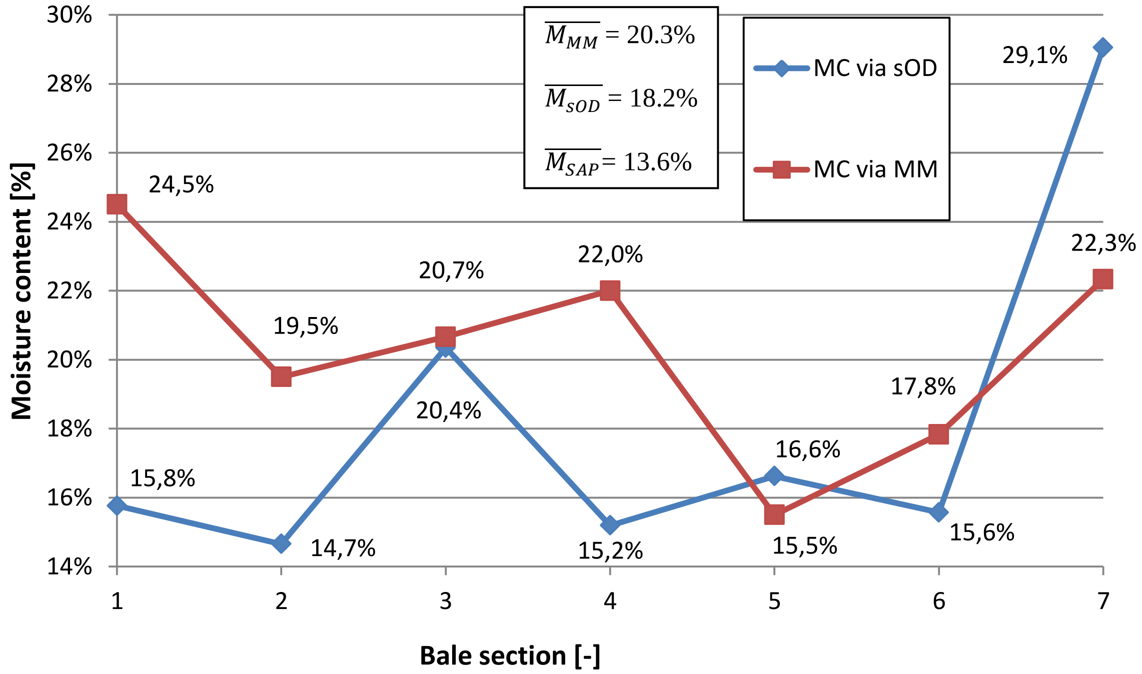

Figure 38. The moisture content along the bale 1.05 – 105698.

The average values of the three compared techniques are stated inside of the boxes. The moisture content via SAP system shows always very low values. This is a proof of described facts in the previous chapter. Particularly, it describes the low values of MC in Figure 22. Continuously, a new sophisticated oven-dried technique is working well and shows very comparable MC value as MM technique.

6.5 Dependency of moisture content and bale density

Base on the equation (2), one can state that bale density is the function of water mass inside of the bale as equation (3) shows

$$\rho_B = f(m_W) \tag{3}$$

where $\rho_B$the bale density, and m_W is the water mass inside of the bale. Moisture content MC is described as water mass divided to the total mass

$$MC = \frac{m_W}{m_B} \quad [\text{kg/kg}] \tag{4}$$

where m_W is the water mass inside of bale in kilograms and m_B is total bale mass in kilograms.

This assumption is crucial. As a result, it is possible to construct density dependencies for each value of moisture content.

6.5.1 Density/moisture dependency construction

There were checked 14 waste paper bales via three techniques. These results are shown in three dependencies, which can be found as Figure 39, Figure 40, and Figure 41. Each point represents certain value of MC measured inside the bale with certain density.

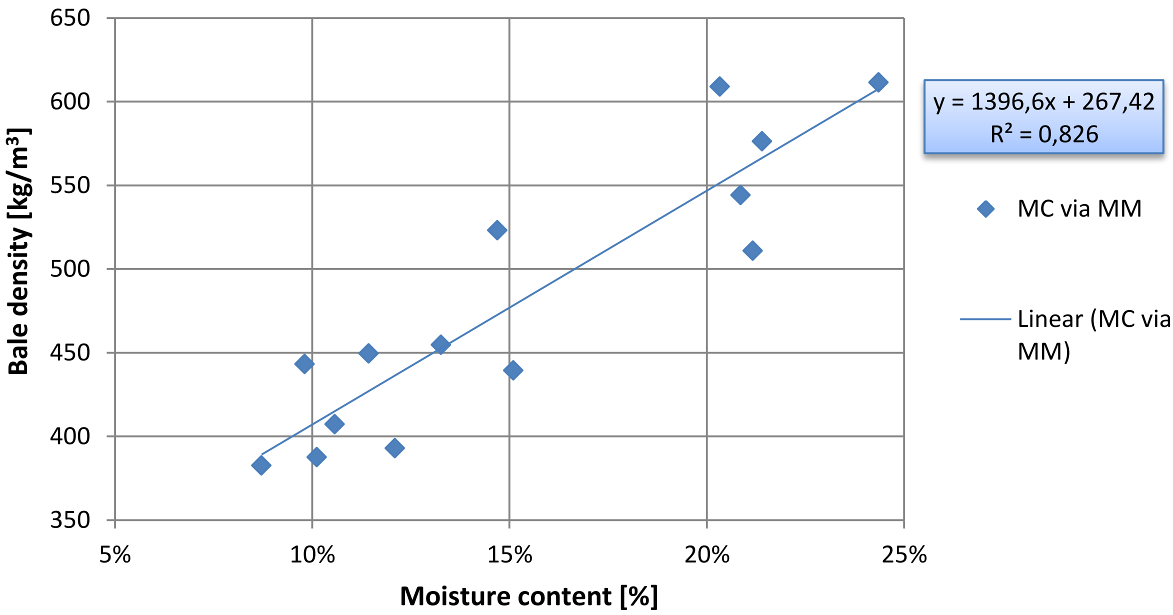

Figure 39. Dependency of moisture meter technique.

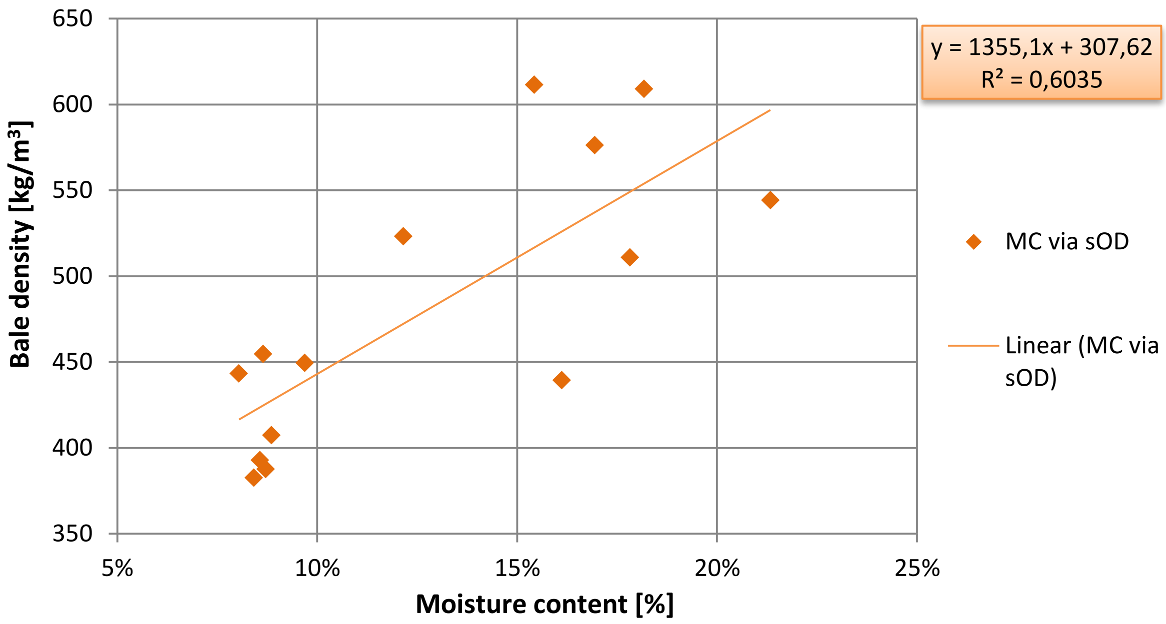

Figure 40. Dependency of sophisticate oven-dried technique.

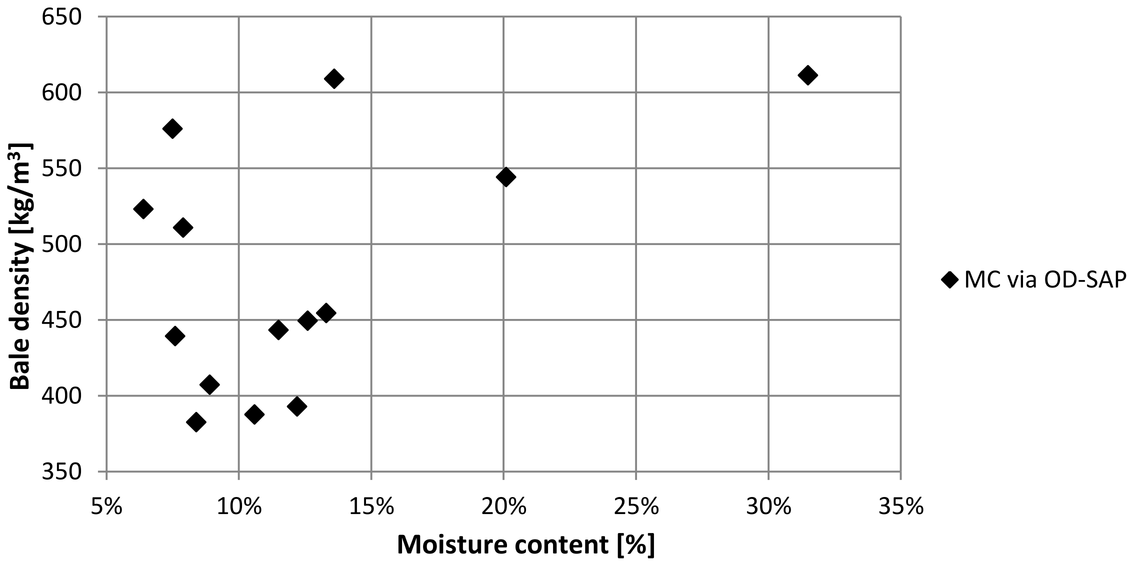

Figure 41. Dependency of oven-dried technique (from SAP).

Dependency of MM technique shows very optimistic results Figure 39. It is apparent linear trend of MC values. If the bale density is rising, than the MC is higher as well. Correlation coefficient R2 = 0.826, thus the strength of the linear relationship is strong.

Dependency of sOD technique shows very similar trend in Figure 40. Only differences are in dispersion and the correlation coefficient, when R2 = 0.604. It can be explained, that the amount of checked paper mass via sOD technique is much lower, than the amount of mass via MM technique.

As we can notice in Figure 41, values of OD technique (from SAP) are very low. Most of them are under 15% level of MC. In contrast, with the other two techniques, it is impossible to construct any trend-line. Moreover, there is no function between the bale density and moisture content. The stated fact is another proof, which confirms wrong values via OD technique (from SAP).

6.6 Results of the moisture meter technique

According the theoretical assumption and measured data, one can consider that the MM technique is reliable moisture characterization technique. It is based on several facts:

1. MM values correspond with sOD Values.
2. Moisture meter checks a huge volume of paper mass.
3. Inner conditions of the bale are kept – the bale is not burst before the single measurement.
4. The dependency of the bale density and the moisture content is linear, with a strong correlation coefficient.

Advantages of the MM technique:

- Quick measurement of a huge amount of mass.
- The display immediately shows an average value of several measurements.
- Measured data is more precise.
- Data is transformed to an excel file on the computer.
- Device mobility.

Disadvantages of the MM technique:

- Sensibility of ambient conditions.
- Sensibility of metal rejects inside the bale.
- Sensible design.
- Importance of careful handling and storing.

The approaches and the knowledge of handling the moisture meter are attached in appendix PI. Appendix PII summarizes the technical data of this equipment.

7 PAPER BALE LABORATHORY MODELS

There is theoretical assumption of the equation (3), that the MC is function of density. The MM technique and sOD technique particularly confirm the assumption. However, its validity is not clearly approved. In order to achieve clarification, the laboratory experiments were approached. The aim was to prove the dependency of bale density and moisture content. If the linear growing trend was presented in a minimized laboratory bale, the trend would be valid in real bales as well.

There were tested various types of bale models such as kraft sheet model, paperboard sheet model or recovered bale models. Additionally, the experiments were performed with fixed moisture content as well as with fixed oven-dried mass. These series of experiments can provide important information, what exactly happens inside of paper bales while the bale is pressing.

7.1 Hand-press apparatus

During the internship, physical laboratory was accessed for M/D experiments. It was equipped with many paper and board testing instruments. The old press apparatus from William Apparatus Co was situated among all of them Figure 42. Normally, researches use this equipment with metal container for pulp pressing.

Metal container in Figure 44 is the box form equipment with the top side which is opened. The inner space is divided by a pocket with a foraminate walls, thus excess water can leave through the wall from the pressing mass easily. The container consists of two holes in the bottom corners. While the paper mass is pressed, they lead the water out of this equipment.

However the equipment is handle-operated, the pressing force is described by pressure meter, which is constructed within HPA.

Figure 42. Hand - press apparatus with inserted metal container.

7.1.1 Pressing features

The old HPA was manufactured in USA. Admittedly, the pressure meter showed very suspicious values. Anyhow, all the measurements were performed very carefully and precisely in order to eliminate an error aspects. For instance, the hand-press experiments were preceded always in the same manner and the stroke height was checked four times and finally the average value was estimated. Also, the pocket area dimensions were checked ten times along its length and the average value was calculated. In overall, good and satisfactory results were provided.

The disadvantages of HPA technique:

- Old equipment.
- Pressure meter probably gives wrong values.
- Pocket area dimensions are approximated, because they vary along their length (approximately 3mm).
- Possible error of stroke height.

The advantages of HPA technique:

- HPA experiments give a true character of M/D trends.
- Pressure force was always performed by same hand power.
- Total control of moisture content of pressed mass.

7.1.2 Designed approaches

Several pressing approaches were performed. The experiments differed from pressed mass composition and the constant quantity:

- Sheet models with fixed oven-dried mass.
- Recovered bale models with fixed oven-dried mass.
- Recovered bale models with fixed moisture content.

A variety of experiments were performed with HPA, nevertheless some of the aspects were kept for all measurements.

Moisture content regulation – an approach was created in order to keep the exact information of moisture content MC. It is based on the equation (5).

$$MC = \frac{m_M - m_{OD}}{m_M} = \frac{m_W}{m_M} \quad [g/g] \tag{5}$$

where m_M is the total mass weight of the bale model in grams, m_{OD} is the oven-dried mass of paper in grams, and m_W is the water mass inside of the bale model in grams.

At the beginning, the samples were dried in the oven, what provided the precise value of oven-dried mass. At this state, one can calculate the moisture content, which is equal to 0%. The sample mass is equal to the oven-dried mass, so there is no water content. After oven-dried mass determination, the water could be penetrated from laboratory ambient (up to 6-8% of MC) or artificially by watering. Therefore, the increasing water content affects total moisture content. The mass regulation was processed on laboratory balances (Figure 43).

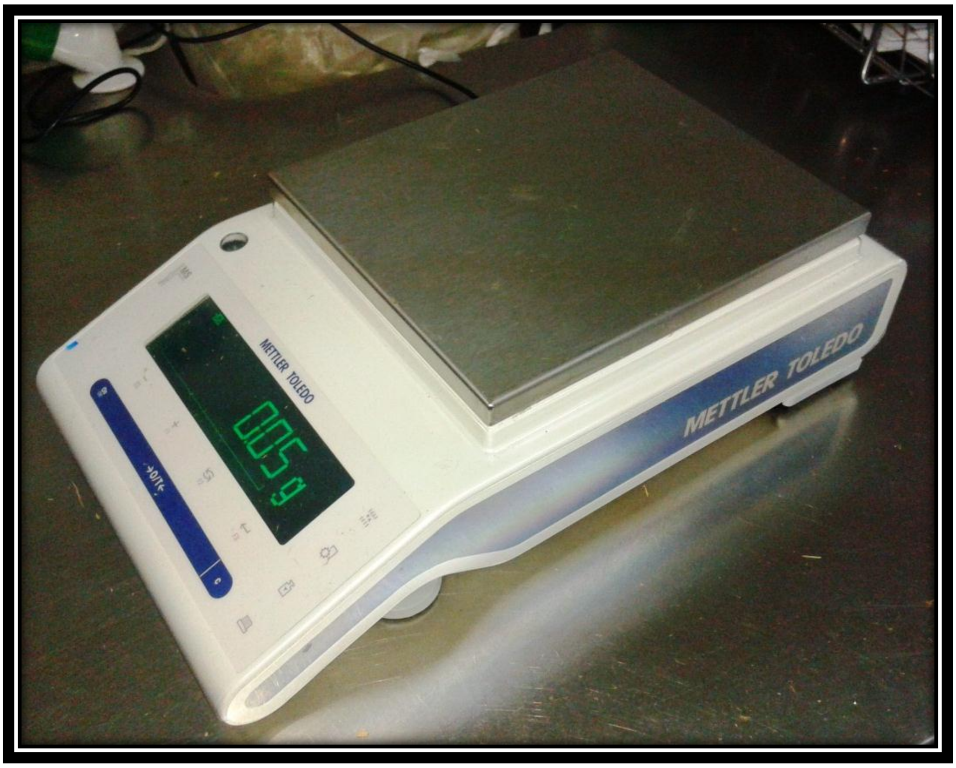

Figure 43. Balances Mettler Toledo – NewClassic MF.

Constant pedestal dimensions - the dimensions of the metal pocket pedestal are 24.7 x 24.6 cm. The pressed mass was being moulded into the pocket of the container (Figure 44), thus the pocket represented constant pedestal dimensions of bale model. The height was measured as a stroke height of the HPA by micrometre. Finally, the bale model volume and the density were calculated within the bale model dimensions and the total model weight.

Density/moisture dependence – according to the various moisture contents and densities, a D/M dependence was constructed. The trends of these graphs provide valuable information about the bale model behaviour during the pressing.

Constant pressure – the constant value of pressure force was being kept during the all measurements. Every model dimension check was performed in the maximum compressed state. The aim was to compact the bale as much as possible. Thus the pressure could be described as a maximum pressure. The value was checked on pressure meter in psi unit and recalculated to kPa unit by equation (6).

$$1psi = 6894.75\,Pa \tag{6}$$

Experiment's conditions – every measurement was performed in the physical laboratory with the controlled ambient humidity (50%), the temperature (25°C) and the atmospheric pressure (101kP). These conditions affected the experiments minimally.

Figure 44. Metal container within inserted paper mass into the pocket.

7.2 Sheet models of paper kraft and board

7.2.1 Designed approach

The technique was designed for M/D dependency and V/M description. The aim was to find out the exact relation between MC and the paper density under the pressure force.

All sheet samples were cut to the same dimension (23x21cm) and placed on the top of each other. By layering of numerous 2D plane sheets, a 3D solid bale models were created. They had layered structure with exact dimensions of pedestal. Basis weights and board types were varied:

- Kraft sheet – the paper kraft was produced in Europac (Figure 45). Various grades were checked, such as:
  a) 115 g/m^2.
  b) 186 g/m^2.
  c) 275 g/m^2.
- Board sheet – two types of paper boards were checked (Figure 46 and Figure 47), such as:
  d) Virgin board – It was a brand new product; hence it hadn't been used before.
  e) Recovered board – It was delivered among the waste paper, hence it had been used before. The samples were taken from a bale grade 1.05.

During the sheet model experiments, some values were kept for every check. These values are shown in Table 3.

Pedestal dimensions [cm]	21 x 23
Pressing force [kPa]	200
Moisture content range [%]	5 - 50
Oven-dried mass	Fixed

Table 3. Sheet model experiment inputs.

Figure 45. Sheet model of kraft paper.

Figure 46. Sheet board samples – recovered board in the middle and virgin board on sides.

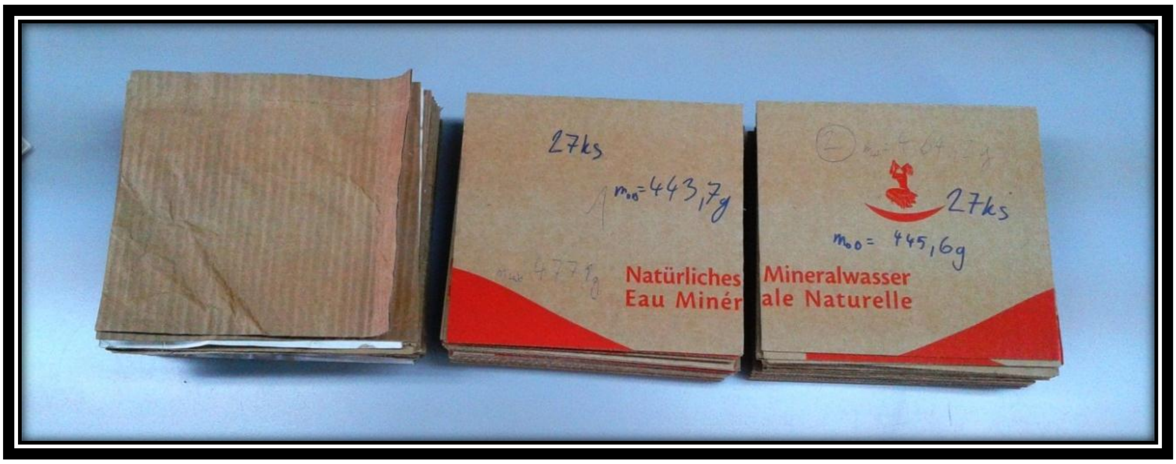

Figure 47. Sheet board samples – pedestal is equal to each other.

7.2.2 Experiment's procedure

Each measurement was performed with HPA. Models were moisturized and weighted m_m. With equation (5) it was calculated moisture content of each model. Therefore, the model was pressed in apparatus. The values of height h were measured after pressing. Dimensions of pedestal a x b were 21 x 23 mm. Therefore the bale model volume V_M is calculated as well as the bale model density ρ_M by equation (7). This procedure was executed approx. 15 times, until the maximum MC of the model was reached. It was signified by leaked water from the pressed mass.

$$\rho_M = \frac{m_M}{V_M} = \frac{m_W + m_{OD}}{a \cdot b \cdot h} \qquad \left[\frac{g}{cm^3}\right] \tag{7}$$

7.2.3 Experiment's results

The results of M/D dependency are shown in Figure 48. Trends of the board curves are logarithmical and the kraft curves are polynomial. So the MC is a function of the bale model density. Therefore the equation (3) was proved by this experiment. Moreover, it was absolutely proved, that the density always rises with the moisture content, while the OD mass is constant and the press force is constant as well.

Different logarithmical and polynomial slopes are determined. Be the comparing a slope of curves with Figure 49, one can say that the M/D trend slope depends on the volume change. For instance, the KSM volumes grow linearly with moisture content. These models are pressed perfectly, because spaces between sheets are merged to each other [2]. Continuously, the KSM curve of the M/D dependence is polynomial and it raises much sharper then the BSM curves. The RBS volume decreases along moisture content, what influences the M/D trend and makes it logarithmical. A special case is the VBS model. At the low MC, the volume decreases and it reaches a constant value. Therefore it starts rising with higher MC very slightly. This fact makes M/D trend logarithmical as well.

One can look on trends in the margin of 5-30%, despite of moisture range of real bale. This relation can be simplified to linear regression, what helps to develop a new technique of moisture content determination in the following chapters.

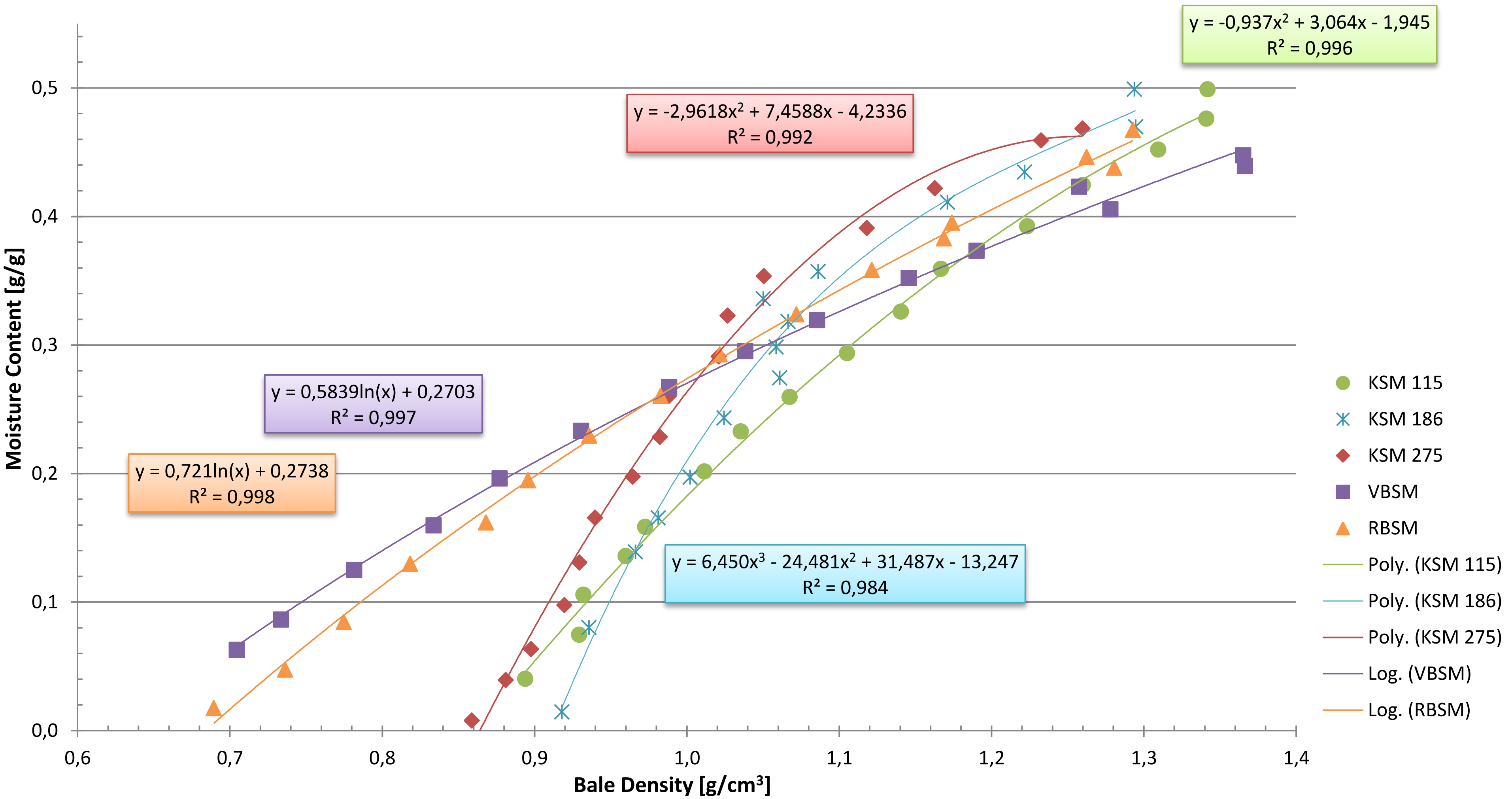

Figure 48. Moisture/density dependence of kraft & board sheet model.

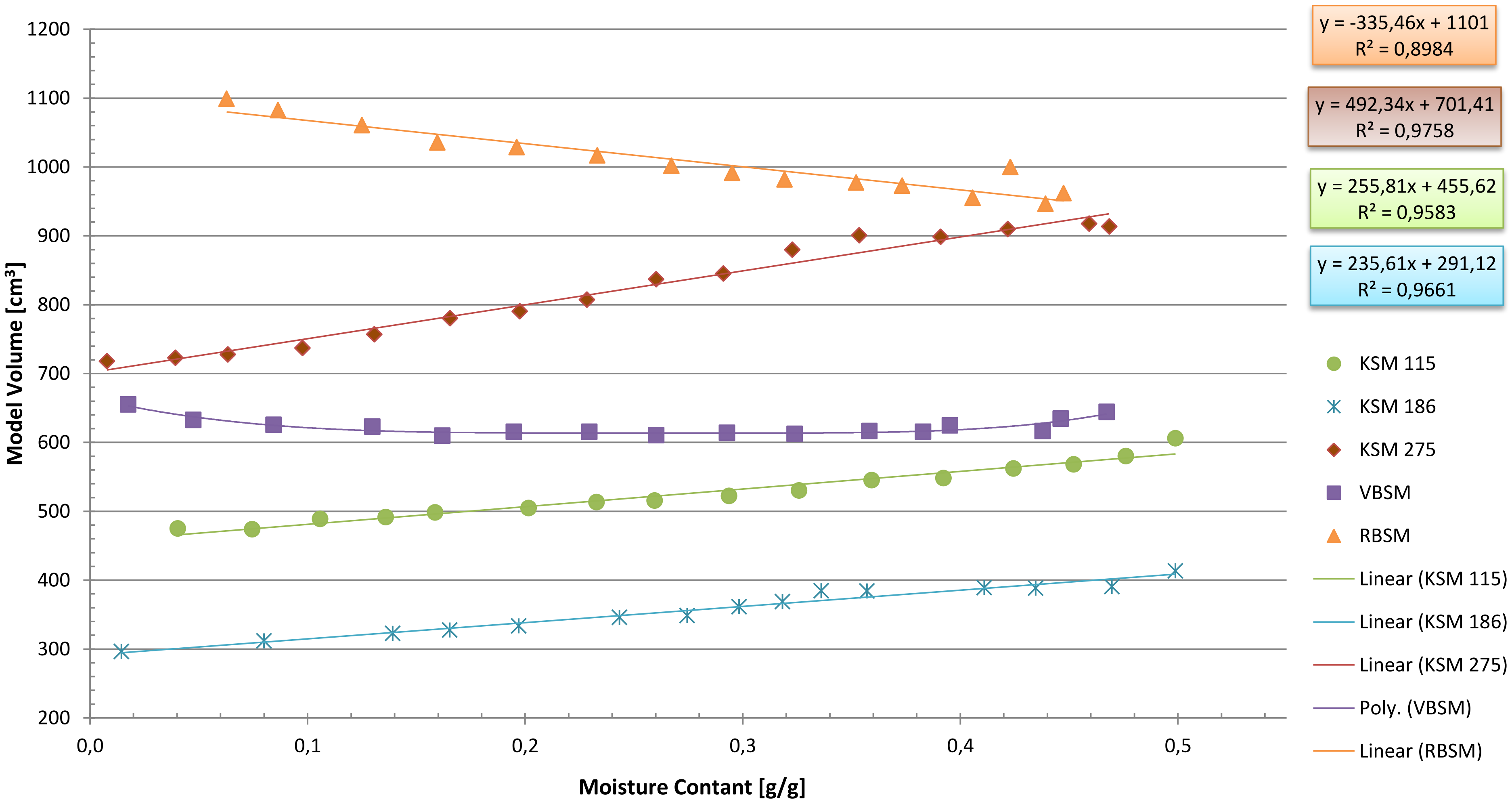

Figure 49. Volume/density dependence of kraft & board sheet model.

Another interesting fact is the maximum moisture content under the given pressure. The maximum value is about 50%. Thus the pressed kraft and board mass can receive only such an amount of water, which is equal to the oven-dried mass.

7.3 Recovered bale models with fixed OD mass

7.3.1 Designed approach

The aim was to create a minimalized bale model and to construct M/D and V/M dependencies. The compositions of various bale grades were simulated during the experiment:

- RBM 1.05 – a recovered bale model without residues content. It contained only recovered paper sheets of 1.05 RP bale grade, which were strapped and formed as Figure 50 shows.
- RBM 1.05-R – a recovered bale model within residues. Recovered paper samples came from 1.05 RP bale. Moreover, it contained a various residues such as small pieces of plastics and metals (Figure 51). Residues example is shown in Figure 53.
- RBM 4.03 – a bale model, which did not contain residues. RP pieces were taken from the bale grade 4.03. It differed in a structure and board type, what shows Figure 52.

During the RBM experiments, some values were kept for every check. These values are shown in Table 4.

Pedestal dimensions [cm]	24.7 x 24.6
Pressing force [kPa]	200
Moisture content range [%]	5 - 50
Oven-dried mass	constant

Table 4. Recovered bale model experiment inputs.

7.3.2 Experiment’s procedure

Each measurement was performed by HPA. RBM were composited by samples, which were taken from real recovered paper bales. The samples were dried inside of oven and weighted for OD mass determination. Therefore, they were striped to random dimensions and arranged to the pocket of metal container. Based on equation (5), the actual MC was described before every press. Also, the model dimensions were checked in each compressed stage and the density was calculated by equation (7).

While the moisture content was rising, the 15 presses were accomplished. The increase of MC inside of the bale was performed by artificial watering. The final measurement of each bale was determined, when the water leaked out from the pressed bale model.

Figure 50. Recovered bale model 1.05 without residues.

Figure 51. Recovered bale model 1.05 within residues.

Figure 52. Recovered bale model 4.03.

Figure 53. Residues of the bale.

7.3.3 Experiment's results

A Figure 54shows the M/D dependency of performed experiments. Trends are logarithmical and very similar to each other. The RBM-R is moved to the left a little bit, what does not make a big difference. Probably, residues caused this difference.

The most important fact is the linear trend between 5% - 30% of the MC. Thus, the MC is strong function of model density.

A Figure 55 shows, how paper loses mechanical properties within moisture arise. It increases the compressibility, while paper fibres slide easier to each other. These fibres are moulded better within the higher moisture content, thus the volume decreases. After, the density is grooving with higher MC sharper, what makes a logarithmical trend in M/D dependency. This fact is seemed within board sheet model as well.

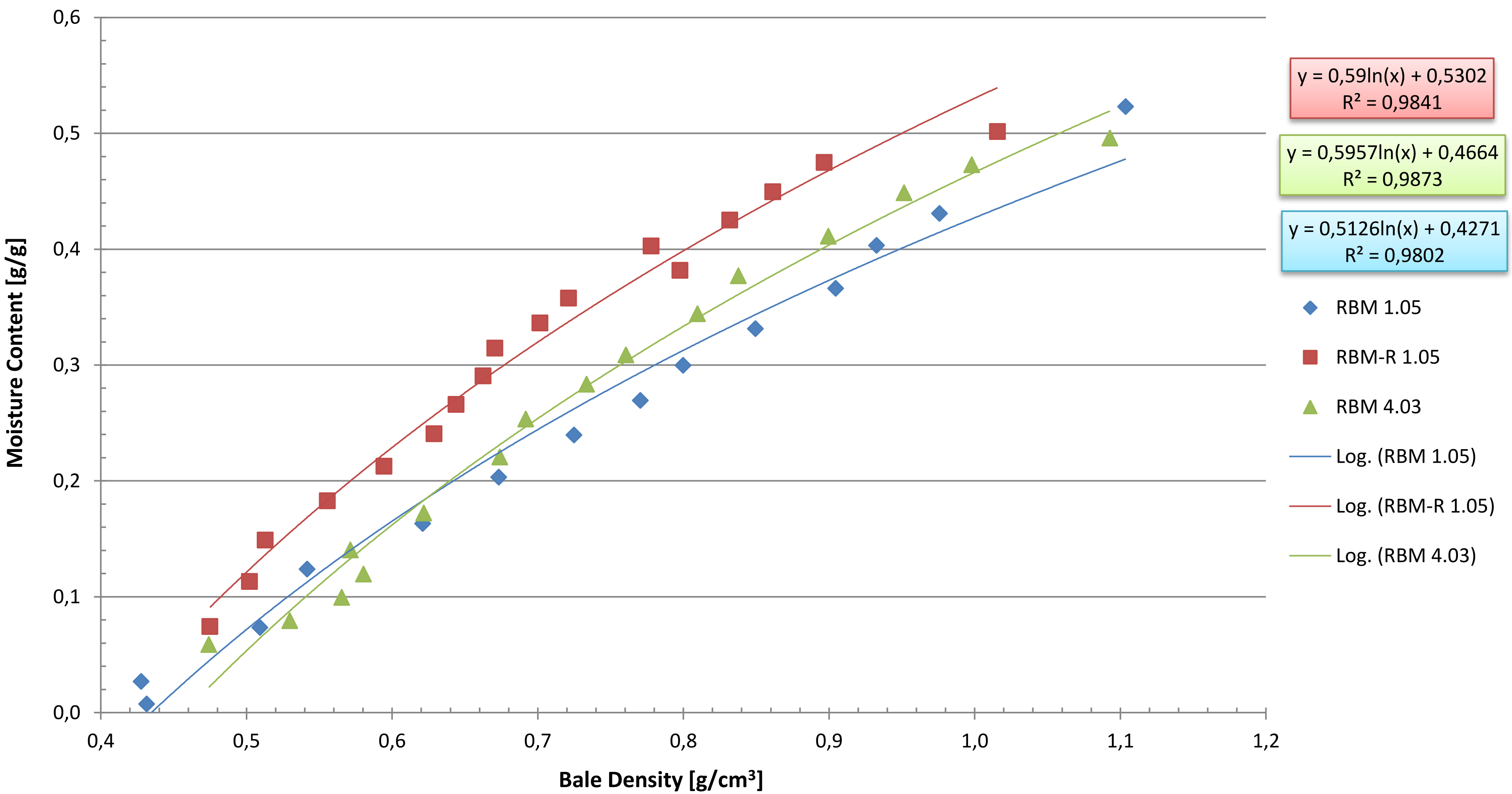

Figure 54. Moisture/density dependence of recovered bale models.

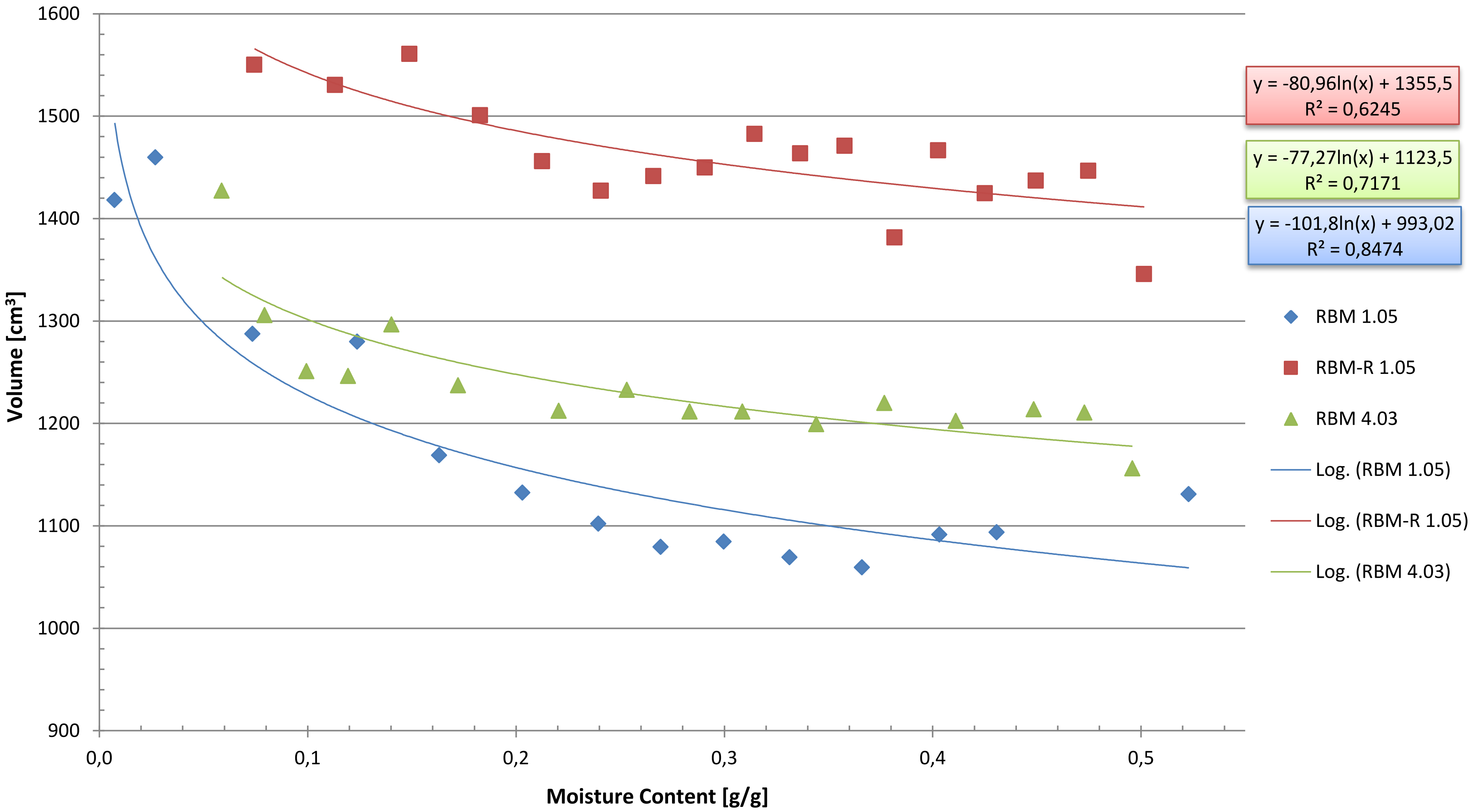

Figure 55. Volume/moisture dependence of recovered bale models.

7.4 Recovered bale model with fixed MC

7.4.1 Designed approach

The main aim was to have a closer look into the range between 5-30% of MC. The secondary aim of this experiment was to check the bale model at constant MC and with total mass arises. In other words, the OD and water masses were being increased within fixed MC. The amount of water and OD mass had to be calculated before every measurement..

The RBM-R bale models were checked same as the Chapter 7.3.1 described. Following moisture stages were checked:

- MC=8.7% ± 0.5%.
- MC=15.8% ± 0.5%.
- MC=24.5% ± 0.5%.

7.4.2 Experiment's procedure

Each measurement was performed by the HPA. The RBM-R was composited by samples, which were taken from the real recover paper bales. After drying and discovering the OD sample mass, they were striped to random dimension and arranged to the pocket of metal container. Therefore the water mass were added continuously with oven-dried mass of paper. Amounts of added mass per one measurement were calculated before, thus the constant MC was kept in the constant value. Based on equation (8), the actual MC was described before every press. Also the model dimensions were checked in each compressed stage and the density was calculated by equation (7). This procedure was repeated 10 times for each MC stage.

$$MC = \frac{m_M - m_{OD} - m_R}{m_M} = \frac{m_W}{m_M} \quad [g/g] \tag{8}$$

where m_M is the total mass weight of the bale model in grams, m_{OD} is the oven-dried mass of paper in grams, m_R is the residues mass of paper in grams, and m_W is the water mass inside of the bale model in grams.

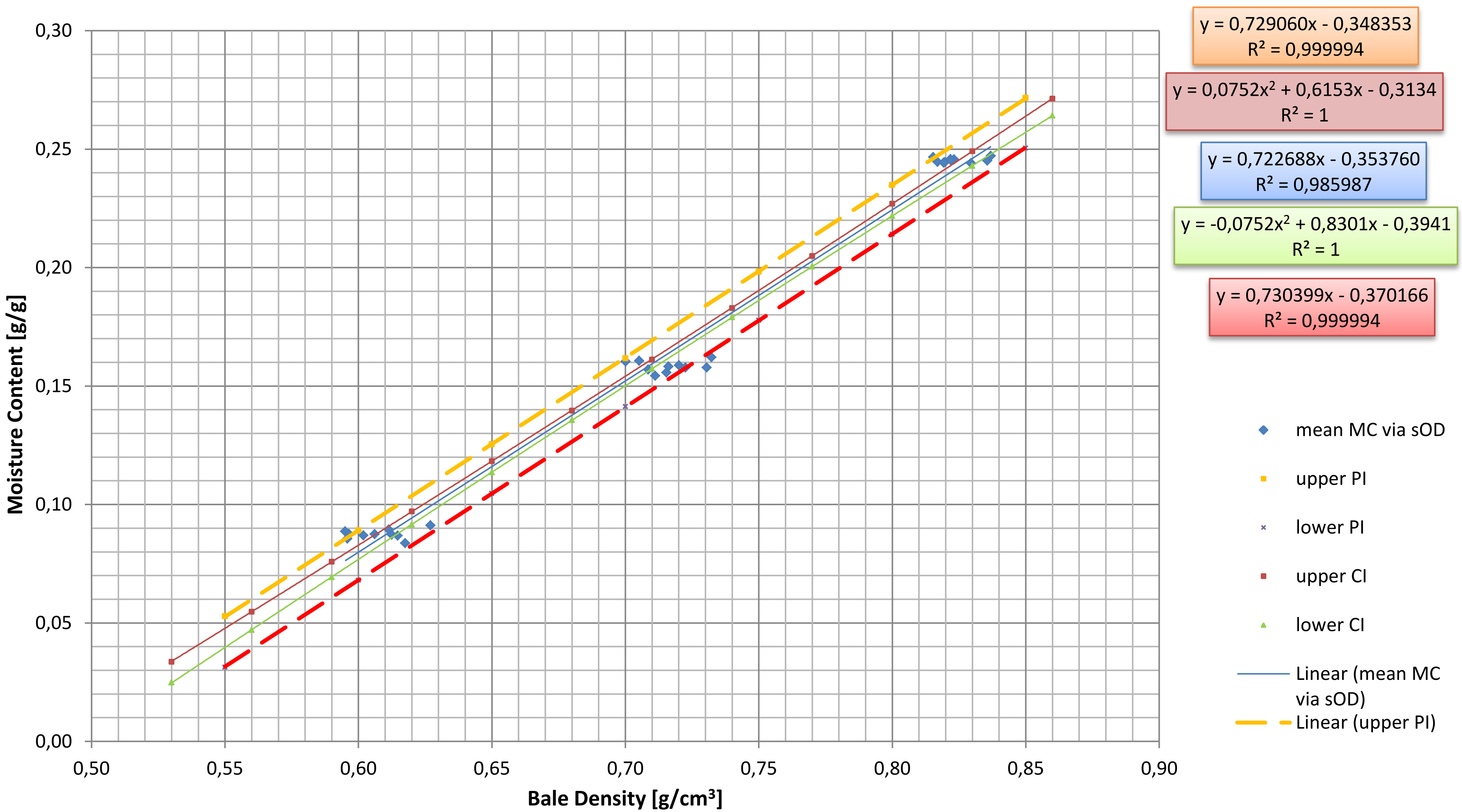

Figure 56. Moisture/density dependence of RBM-R within 80% confidence and prediction intervals.

7.4.3 Experiment's results

Figure 56 shows results of the experiment. There were checked three stages of MC and ten density values per each stage were obtained. The linear trend confirms the assumption of MC and density relation. There were constructed confidence bands, which can be applied only theoretically, because of the high difference between stages. Nevertheless, one calculates the MC base on the density, because 80% of points are bounded by prediction bands. Predictions bands are simplified to the linear curve which R^2=0.99 and their line equations are known. The prediction interval width is 2%.

This statement is practically valid, only if the linear regression is constructed by many points of MC along all the density line. However, this is an important fact, which provides solution for a new moisture determination technique.

8 DESIGN OF A M/D TECHNIQUE FOR MC DETERMINATION

Based on the previous experiments, it was summarized background for inventing a new approach for moisture prediction of real bales. Technique was established on following foundation:

- M/D linear regression - It was proved, that the MC of pressed bale model is function of bale density. At the constant pressure, the regression was linear among 5 – 25% of MC. Correlation coefficient R^2=0.98, thus the trend was very strong. The experiments of RBM with constant MC level shown possibility for MC prediction within application of confidence and prediction bands.
- Moisture meter validation – The values, which were measured by moisture meter, shown the most satisfactory results. Thus, the M/D dependency of real bales was created by MC values via MM.

8.1 Designed approach

In Chapter 6, it was performed the experiment with moisture meter. Final M/D via MM dependency shown linear regression, unlikely it was created by 14 measurements only. The aim of following experiment is to improve this dependency and to construct reliable dependency based on many measurements.

Implicated procedure was similar as in Chapter 6. Each bale was checked 12 times by moisture meter. Therefore the average MC was calculated. The bale dimensions were taken and continuously the weight of the bale as well. By the equation (2), the bale density was calculated. This value was related to MC value, what is shown in the Figure 57.

8.2 Real Bale M/D dependency and the correlation analysis

Based on 50 measurements, the M/D dependency via MM was constructed in Figure 57. Correlation regression coefficient R^2=0.739, thus the linear regression is strong enough. Confidence bands are constructed within confidence level of 80%. The prediction bands were constructed as well within the same confidence level [14]. Thus the mean MC value belongs to the bale density value, within the width of confidence interval. The mean of MC with its confidence interval vary into the prediction interval, which is bounded by prediction bands. Thus the MC prediction is possible, if the bale density ρ_B is determined. For instance, for the density of 580kg/m^3, it is predicted the MC content of 20% ±2.7%.

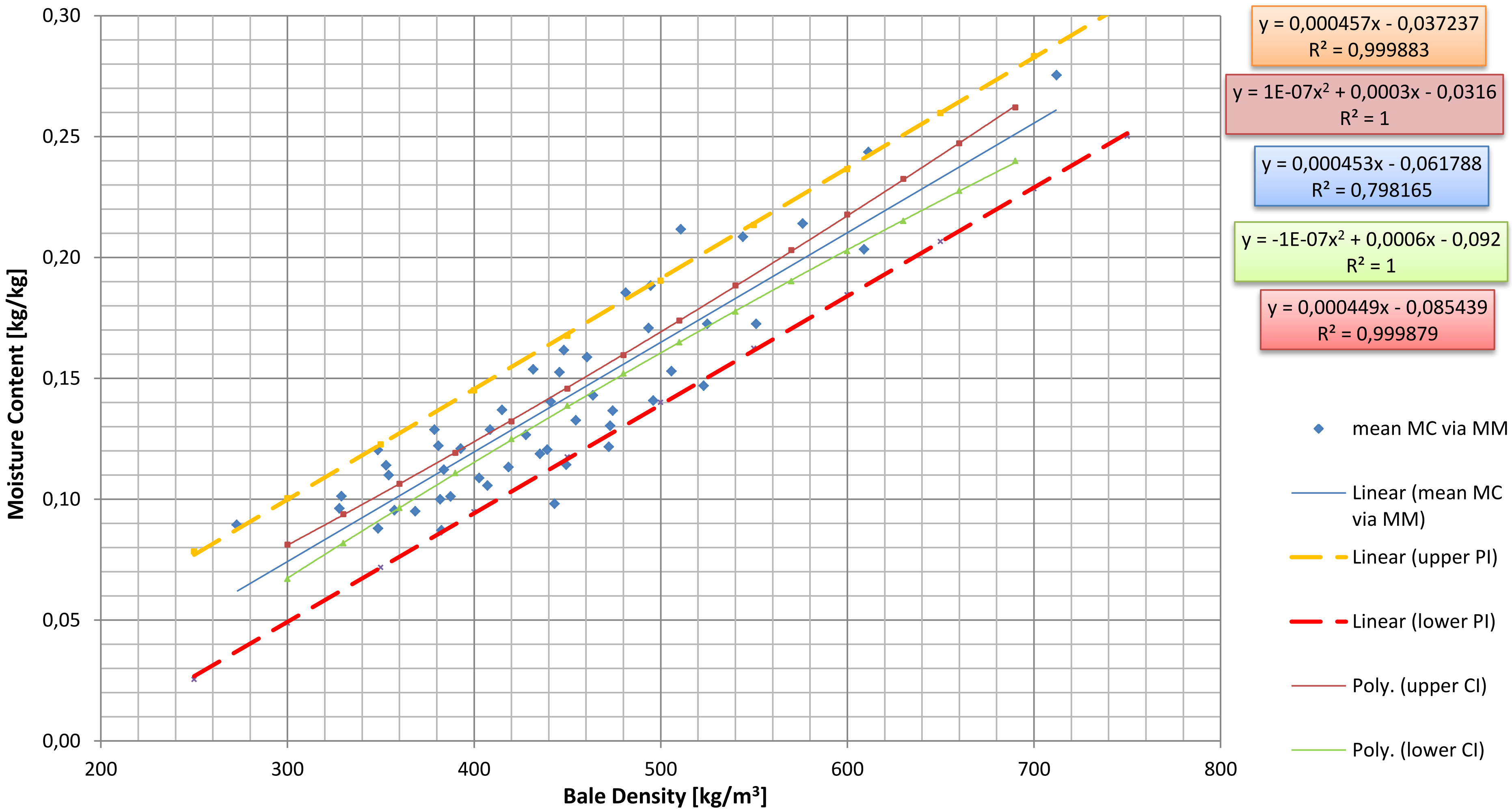

Figure 57. Moisture/density dependence of RRB within 80% confidence and prediction intervals.

Trends of prediction bands supposed to be slightly polynomial as well as the confidence bands. For practical reasons, these points were overlapped by curve with linear trend. The correlation coefficient is R^2=0.999, thus prediction points are related to this linear curve excellently. This step helps to calculate lower and upper predicted MC values much easier. The mean value is calculated by linear regression equation. Finally, there are three calculated values:

- Mean MC predicted value - MC_{mean} - it represents the predicted mean value of linear regression – equation (9).
- Upper MC predicted value - MC_{max} - it represents maximum MC calculated by upper prediction interval – equation (10).
- Lower MC predicted value - MC_{min} - it represents minimum MC, which is calculated by lower prediction interval – equation (11).

$$\boldsymbol{MC_{mean} = 0,000453 * \rho_B - 0,061788} \tag{9}$$

$$\boldsymbol{MC_{max} = 0,000457 * \rho_B - 0,037237} \tag{10}$$

$$\boldsymbol{MC_{min} = 0,000449 * \rho_B - 0,085439} \tag{11}$$

8.3 Estimation of the moisture content

Following values of recovered bales inside the lorry are identified:

- Total load mass – every lorry is balanced at the entrance and at the exit of factory. Therefore, the total recovered paper mass, which is unloaded in factory, is calculated by the difference. The value is recorded in SAP system.
- Number of bales – Number of bales is known inside of each lorry. The value is recorded in SAP system.
- Average bale volume– Dimensions of bales in single lorry are similar, but not the same. Differences are approximately 10-15cm by side size. Dimensions of three bales were checked in pressed form and the average volume was calculated.

Now, it is possible to estimate average bale density $\overline{\rho_B}$ with following equation of average bale mass weight $\overline{m_B}$ and average bale volume$\overline{V_B}$:

$$m_L = m_{EXIT} - m_{ENTER}\ [kg] \tag{12}$$

$$m_L = \sum_{i=0}^{n} m_i\ \ [kg] \tag{13}$$

$$\overline{m_B} = \frac{m_L}{n}\ [kg] \tag{14}$$

where m_L is the lorry load mass, which is calculated as difference of lorry weight at exit m_{EXIT} and lorry weight at entrance m_{ENTER}. Single lorry load mass is divided by number of bales n in single lorry load.

$$V_{Bi} = a_i + b_i + l_i\ [m] \tag{15}$$

$$\overline{V_B} = \frac{V_1+V_2+V_3}{3}\ \ [m] \tag{16}$$

Where $a_i, b_i, and\ l_i$ are dimensions of i picked bales for estimation of average bale volume $\overline{V_B}$. Particular volumes of three picked bales are$V_1, V_2, and\ V_3$.

$$\overline{\rho_B} = \frac{\overline{m_B}}{\overline{V_B}}\ [kg/m^3] \tag{17}$$

The finally average density of the bale in single lorry load $\overline{\rho_B}$ is calculated.

The volumes, bale numbers and total masses were measured on 33 lorry loads. They represent 833.5 tons of recovered mass. The mill consumes this mass approximately in single week.

After discovering of average bale density of each lorry, the MC values were calculated by equation (9), equation (10), and equation (11). These MC values were compared with MC values from SAP system (OD present technique). Results are shown in Figure 58.

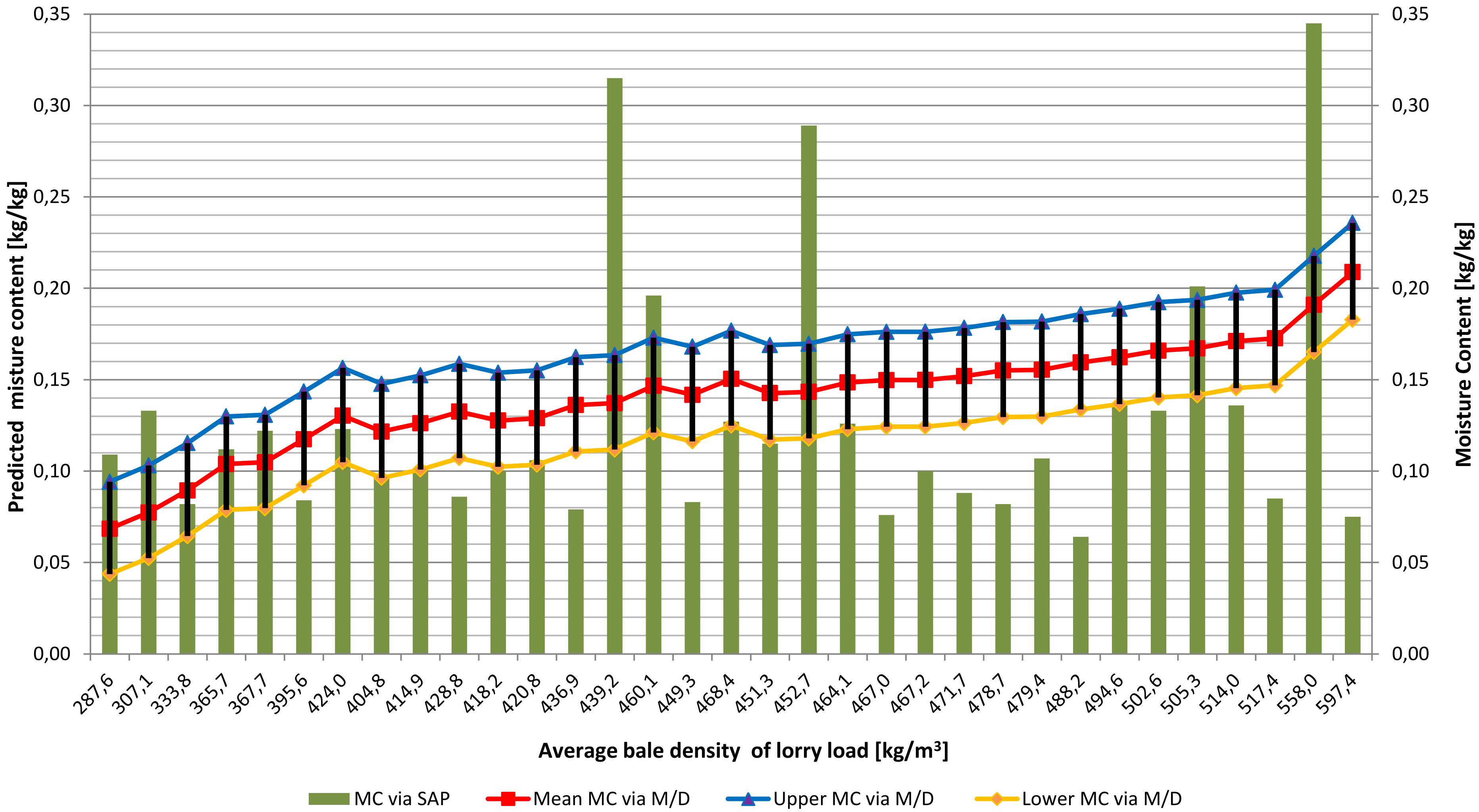

Figure 58. Final comparison of predicted values via OD-SAP and via M/D dependency.

8.4 Predicted values comparison

Several cargo densities predicted via OD-SAP differ a lot. Extremely high difference (approximately 15% of MC) is seen at three examples. Probably an operator took a sample from the bale, which did not correspond with the total mass of lorry load. In opposite, the M/D technique is complex and it counts within whole mass and the whole volume. OD-SAP technique is very accidental. Sampling of so huge mass (20-30tons) within so strong non-uniform feature is very incorrect.

Nevertheless twelve OD-SAP measurements match the prediction area of M/D values, which work within ±2.7% prediction error. The OD-SAP estimation error is not described. Table 5 shows the comparison of the two techniques.

The cost of recovered paper is various by region and it changes by month. On October 2011, the price of old corrugated containers (grade 1.05) was approximately 130Eur per tonne in Europe.

	Density Technique	**OD technique (SAP)**
Checked mass per lorry load	~ 25 000 kg	~ 0.35 kg
Checking time	15 minutes	24 hours
Bale bursting	NO	YES
Type of checked mass	Waste paper + rejects	Waste paper
Estimation approach	• complex calculation • average values are estimated	• Random sampling of non-uniform huge mass

Table 5. M/D technique and OD-SAP technique comparison.

	Density Technique	**OD technique (SAP)**
Average MC	14.0 %	12.8 %
Error	±2.7%	-
Paid water instead of fibre per week	34.7 ±16.7 tones	23.5 tones
Possible saving per week	4510 ±2167 Eur	3060 Eur

Table 6. Financial saving comparison of M/D technique and OD-SAP technique.

8.5 M/D technique conclusion

A new technique for moisture content determination was described. So far, it shows the most reliable values among all of performed techniques. It works on the linear regression of moisture/density dependence. Linear behaviour was described mathematically same as experimentally in laboratory. In the case of application the M/D technique, the cost saving will be app 1500Eur higher than with present OD-SAP technique.

M/D technique advantages:

- Complexity – technique counts the complete mass of delivered recovered paper load. The non-uniform effect is avoided.
- Simplicity – the only measured value by operator are dimensions. The cargo mass and the number of bales are checked at the entrance of the factory.
- Reliability – According to the M/D linear regression via MM, the technique works in the prediction area ±2.7% of the mean MC.

Density technique advantages:

- Various pressure forces – Each supporter of recovered paper uses different pressure force for compressing the waste paper into the bales. Afterwards, various bales within various densities could to have same moisture content.
- Various Bale compositions – Bale grades 1.04 and 1.05 have various compositions (paper grades, type and amount of rejects). Thus even under the same pressure force, they are compressed to various dimensions.

Stated disadvantages are minimalized mainly by average calculation. Nevertheless, these disadvantages make an error of the technique.

CONCLUSION

The master thesis collaborates on the new technique of moisture content determination of recovered paper bales. Finally, the new complex technique was developed, which works on the moisture/density linear regression. The predicted error is ±2.7% of moisture content and it is designed for bale grades 1.04, 1.05 and 4.03.

The first part of master thesis contains the theoretical background of papermaking. The structure and the physics of paper were discussed as well. Moreover, the actual trends of recycling in Europe are investigated, which shows a potential to the goal of the master thesis. The market of recovered paper will be growing the same as its consumption. European legislation pushes society to recycle and to use recycled products. In the future, the amount of sources will be only decreased, so the recovered sources will play an important role of production.

The experimental part of master thesis investigates the moisture characterization of recovered paper bales. In spite of the issue in Europac Kraft Viana in Portugal, the new technique development had started. The actual oven-dried technique brought unsatisfactory results. The paper bale moisture profile experiment and drying curve experiment proved the unreliability of the present technique. The reasons are:

- Non-uniform character of bale.
- Not corresponding sample mass with total cargo mass.
- Delay of sampling after bursting the bale.

Another technique of moisture content determination is via the moisture meter AP500-M from Emco Company. The results of this equipment were evaluated as the most reliable in comparison with the oven-dried techniques. The moisture/density linear regression was discovered and the new experiments were designed in the laboratory. Many experiments were performed by using the bale press apparatus, when the real paper bales were minimalized into the paper bale models. All experiments proved the moisture/density linear regression in the range of 5-30% of moisture content.

Using the moisture meter, the moisture/density dependence was improved and enlarged for 50 measured bales. Based on the prediction of linear regression, there were determined equations of the maximum and minimum predicted moisture content for each bale density value. Finally, based on the bale density, it is possible to estimate the mean moisture content of the whole delivered lorry cargo. The predicted error is ±2.7% of MC.

FUTURE WORK:

1. Moisture/density/pressure model

   The aim is to create M/D dependency within various curve trends, which depend on the pressure force. It is possible to apply many waste paper grades. This could be used in waste paper collecting companies, where the MC can be estimated very quickly within the moisture/density/pressure calculation model. When the real bale is compressed (Figure 24), the bale weight and the dimensions are known. Thus it could be applied in the control process of pressing.

2. Moisture/density technique improvement.

   M/D dependency can be modified and improved. The bale density is calculated by dimensions of waste paper bale. Because of various suppliers use different pressure forces, the prediction intervals are too wide. If the density of the bale is measured under fixed pressure force, the prediction interval will be lower than the presence state. This could be applied in paper mills for the inspection of the incoming recovered paper mass and controlling the recovering process.

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LIST OF ABBREVIATIONS

CD	Cross-Machine Direction
CEPI	Confederation of European Paper Industries
CI	Confidence Interval
DC	Dielectric Constant
D/M	Density/Moisture
EU	European Union
ELSGRPB	European List of Standard Grades of Recovered Paper and Board
HPA	Hand-Press Apparatus
kPa	Kilopascal
KSM	Kraft Sheet model
MC	Moisture Content
MD	Machine Direction
m_M	Model Mass
MM	Moisture Meter
M_{MM}	Moisture Content via Moisture Meter
m_{OD}	Oven – Dried Mass
M_{SAP}	Moisture Content via Oven-Dried Technique – from SAP system
M_{sOD}	Moisture Content via Sophisticated Oven-Dried Technique
m_W	Water Mass
OD	Oven-Dried
PI	Prediction Interval
psi	Per Square Inch
RBA	Relatively Bonded Area
RBSM	Recovered Board Sheet Model

RH	Relative Humidity
ρ_M	Model Density
RP	Recovered Paper
sOD	Sophisticated Oven-Dried
VBSM	Virgin Board Sheet Model
V_M	Volume

LIST OF FIGURES

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APPENDICES

APPENDIX P I: MOISTURE METER OPERATION GUIDE

This appendix describes, how to measure use moisture meter correctly and precisely. This knowledge was summarized based on my experience during MM measurements. Firstly, there are some facts about moisture meter AP500 - M:

- Hand – held equipment ⇒ mobile.
- Calibration curve S5 ⇒ for recovered paper grade 1.05.
- Calibration curve S5 ⇒ for used cardboard and paper packaging, minimum 70% corrugated board.
- Works on dielectric measuring principle ⇒ capacity is changed with the various moisture content.
- Operating temperature: 0°C to 40°C.
- Temperature of storage: -20°C to 80°C.
- Measuring range standard: 1-50 % moisture.
- Resolution of display 0.5% and 0.5°C.
- Measuring area (W x L x D) = (110 x 630 x 300) mm.

The measuring and operating the equipment must be provided carefully. The equipment is very sensitive. It is important to avoid of:

- The presence of metals in measuring area.
- The presence of water on the plate of equipment. If the measured surface is wet, it is necessarily to use dry piece of paper to divide the wet surface and the plate of moisture meter.

It is important to keep:

- The plate must to reach the same temperature as the measured paper mass.
- The plate has to have full touch with measured material.

Procedure:

1) Open the box and move the equipment to the paper bale surface.
2) Wait approximately 5 – 15 minutes to reach stable temperature of equipment. The temperature of moisture meter and surface must be same.

3) Softly press the moisture meter to the bale's surface.
4) Put the finger to the button "OK" and wait until the measured value reach stability
5) Press the button "OK" to store measured value
6) Repeat in different places of the bale at least 10 times
7) After measurement press "ESC " to save measured data under the reference number – the average value of measured moisture content is shown on the display
8) Check the next bale or send data to the computer

APPENDIX P II: AP 500-M TECHNICAL DATA

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Innovation and Competence
Development, Manufacturing and Sales

Portable device for moisture determination

emco AP 500-M

Digital index as percentage – water content

Quick mobile moisture determination without sampling,
to detect moisture in
stacks, bales and loose fills of waste paper

- Lightweight, rugged and mobile: feed – metering – storage
- Quick, non-destructive measuring up to 300 mm deep effective
- Factory-made calibration for different material and compressed density
- Digital index in „%“ water content (weight per cent)
- Temperature value to every moisture value
- Temperature compensation of the moisture value
- Data-log-mode:
  - Automatic recording and storage with date and time
  - Entering of vendor data and batch number possible
- Data output of the last series of measurement respectively of all values through interface and USB-adapter to PC or printer
- Performance data analysis via evaluation software in EXCEL, database- and statistic function
- Delivery at wooden chest with test plate and calibration certificate

emco Elektronische Mess- u. Steuerungstechnik GmbH, Mommsenstraße 2, D-04329 Leipzig, Germany
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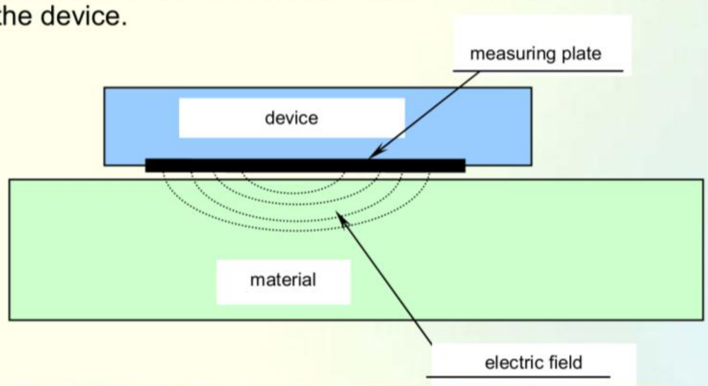
AP 500-M

The used principle to determinate the absolute moisture

The absolute moisture is the percentage water content in a material referring to the anhydrous mass (common for timber) or the total weight (common for paper).

The measuring principle:

The material situated in the measuring area is penetrated of an electric field. Due to the distinctive polarity of the water molecule and the resulting high dielectric coefficient of water (approx. 83) the capacitance of the measuring area varies with the alteration of the moisture in the test sample. Portable measuring instruments refer the measuring signal to a constant volume and assess the moisture values therewith. The measuring field till a deep of 500 mm should be filled completely with the measured sample material. Considerable vitiations like conductive foils, metals and so on lead to extreme differing values or to cutoff of the device.



Technical data

Measuring range:	1 - 50 % moisture
Measuring depth:	300 mm effective, 500 mm maximal
Operating temperature:	0 ℃ up to +40 ℃
Storage temperature:	-20 ℃ up to +80 ℃
Temperature compensation:	0,05 % / ℃
Power supply:	3 AA battery 1,5 V Mignon or NiMH- bzw. NiCd-accumulator
Current consumption:	40 mA
Measured data storage:	approx. 8,000 measurements
Loading condition of battery:	empty = display "BAT"
Resolution:	0,5 % moisture 0,1 ℃ temperature
IP-code:	IP 54
Dimension:	620 x 100 x 150 mm
Weight of device:	875 g
Scope of delivery:	device in wooden box with test plate, certificate and data-transfer-set

Optional accessory: portable printer

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