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COMBINATIONS OF TITANIUM DIOXIDE AND FILLERS IN PAINTS

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Titanium dioxide is a predominant white pigment, which is used as a raw material of paint. Titanium dioxide pigments are produced with both sulphate and chloride processes. In paints, the main function of titanium dioxide is to contribute to the paint film properties, like opacity and whiteness. Because titanium dioxide is a fairly valuable pigment, attempts have been made to replace it with a filler which costs less. Fillers of paint are for instance barium sulphate, kaolin, silicates and calcium carbonate.

The purpose of the work was to study how paint properties change when part of titanium dioxide pigment was replaced with barium sulphate filler so that the filler content in paint was 0, 5, 10, 15, 20, 25 and 30 weight percent. It was also studied how different titanium dioxide grades contribute to paint film properties. The pigments studied were Sachtleben RDI-S, Sachtleben 660, Sachtleben RD3, Hombitan R210 and Hombitan R611 and those were replaced with barium sulphate filler. In addition, the effect of mixtures of titanium dioxide- kaolin and titanium dioxide- barium sulphate on the characteristics of paint film was examined and the effects were compared to those of Sachtleben K40. Colour, gloss, grammage and scattering coefficient were analysed from the paint film and viscosity from the paint. All paints were prepared for both solvent and water-borne paints.

It was noticed in this work that increase of filler content has an obvious influence on paint film properties, like positively on gloss as well as negatively on whiteness and opacity. The paints with Sachtleben RDI-S, Sachtleben 660 and Sachtleben RD3 were top-rated when compared to all studied paints. Taking all results of paints into account, the paints with these three pigments were the most uniform. When Sachtleben Micro was used as filler, results of measured properties were better than those with Amazon Premium.

TITAANIDIOKSIDIN JA TÄYTEAINEIDEN YHTEISKÄYTTÖ MAALEISSA

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Titaanidioksidi on hallitseva valkoinen pigmentti, jota käytetään muun muassa yhtenä maalin raaka-aineista. Titaanidioksidia valmistetaan sekä sulfaatti- että kloridiprosessilla. Maaleissa titaanidioksidin pääasiallinen tehtävä on vaikuttaa positiivisesti maalikalvon ominaisuuksiin, kuten peittokykyyn ja valkoisuuteen. Koska titaanidioksidi on kohtalaisen arvokas pigmentti, sitä pyritään korvaamaan täyteaineella, jonka kustannukset ovat alhaisemmat. Maalin täyteaineena voidaan käyttää muun muassa bariumsulfaattia, kaoliinia, silikaatteja ja kalsiumkarbonaattia.

Työn tarkoituksena oli tutkia, miten maalin ominaisuudet muuttuvat, kun titaanidioksidipigmenttiä korvataan bariumsulfaatti-täyteaineella. Pigmenttiä korvattiin täyteaineella siten, että täyteainepitoisuus maalissa oli 0, 5, 10, 15, 20, 25 ja 30 painoprosenttia. Työssä tutkittiin myös, miten eri pigmenttilaadut vaikuttavat maalikalvon ominaisuuksiin. Tutkittavia pigmenttejä olivat Sachtleben RDI-S, Sachtleben 660, Sachtleben RD3, Hombitan R210 sekä Hombitan R611 ja niitä korvattiin bariumsulfaatti- täyteaineella. Lisäksi tarkasteltiin titaanidioksidi- kaoliini- ja titaanidioksidi-bariumsulfaatti- seoksien vaikutusta maalikalvon ominaisuuksiin ja vaikutusta verrattiin Sachtleben K40:stä valmistetun maalin maalikalvon ominaisuuksiin. Maalikalvoista analysoitiin väri, kiilto, neliöpaino ja sirontakerroin sekä maalista viskositeetti. Kaikki maalit valmistettiin sekä vesi- että liuotinohenteisina.

Tutkimuksessa todettiin, että täyteainepitoisuuden nousu vaikuttaa selvästi maalien ominaisuuksiin, kuten positiivisesti kiiltoon sekä negatiivisesti valkoisuuteen ja peittokykyyn. Sachtleben RDI-S-, Sachtleben 660- ja Sachtleben RD3- pigmenteistä valmistetut maalit olivat parhaita tutkituista maaleista. Mitattujen ominaisuuksien perusteella näistä pigmenteistä valmistettujen maalien tulokset olivat tasaisimpia. Käytettäessä Sachtleben Microa täyteaineena, saatiin parempia tuloksia kuin käytettäessä Amazon Premiumia täyteaineena.

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LITERATURE PART

1 INTRODUCTION

Titanium dioxide (TiO_2) is the most important white pigment and it is used in several applications, like in paints. It is chemically stable, non-toxic and insoluble in bases, acids and other solvents in all normal applications. Titanium dioxide pigments can be produced by two different methods, the sulphate and chloride processes. In paints, titanium dioxide contributes primarily to whiteness, opacity and brightness of paint.

In paints, part of the pigment is replaced with filler so that costs of end product can be reduced. Filler has an effect on gloss, texture, suspension, tinting strength and viscosity of a paint. Fillers are among others barium sulphate, kaolin, calcium carbonate, silicates and silica.

2 RAW MATERIALS OF PAINT

2.1 White Pigments

Pigments are used in paints and other materials to impart colour, opaqueness, and other desirable properties to the product. In paints, pigments may also regulate the gloss, impart anticorrosive properties, and reinforce the film. All white pigments are inorganic compounds. They contain for example TiO_2, zinc sulphide and lithopone. These white pigments are all nonreactive. /1/

2.1.1 Titanium Dioxide

Pure titanium dioxide (TiO_2) is a colourless crystalline solid. It is stable, nonvolatile, largely insoluble, and rendered refractory by strong ignition. TiO_2 is amphoteric, although it is more acidic than basic. It exists in three fundamental crystal forms, namely tetragonal rutile, tetragonal prisms of anatase, and orthorhombic brookite. /2/

Commercially produced crystal form of titanium dioxides are rutile and anatase. Rutile pigments are more important in volume terms. The rutile crystal has a more compact structure than the anatase form (Fig. 1). This accounts for important differences between the two crystal forms, particularly the greater stability, higher refractive index, and higher density of the rutile form. The higher refractive index of the rutile crystal, which leads to its greater opacifying power, and its superior exterior durability are the major reasons for its preferred use relative to anatase. Many anatase pigments are used only in relatively specialized applications where they have been selected because of their blue tone, their ability to operate with optical brighteners, or their lower Mohs hardness resulting in lower abrasivity. /2/

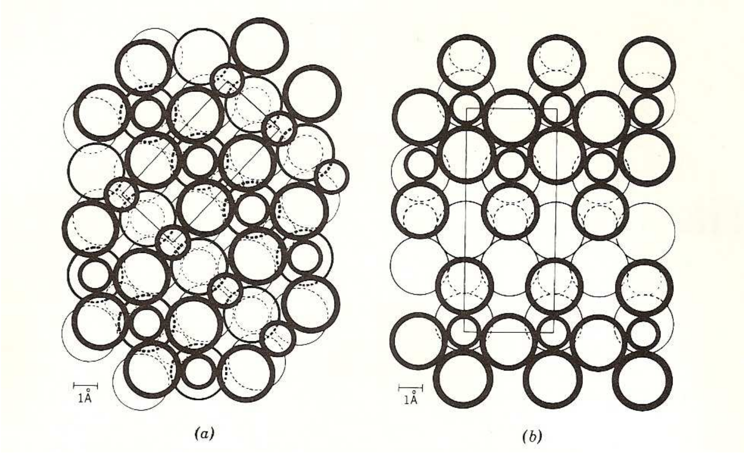

Figure 1. Crystal structures of (a) rutile and (b) anatase titanium dioxide. /2/

Titanium pigments' colour is affected by their purity, because particular contaminants, even at the level of parts per million, adversely affect colour. /2/

2.1.2 Zinc Sulphide

Zinc sulphide has a restricted use as a single pigment. It is mainly important as a component of the composite white pigment lithopone. Of all the white pigments, zinc sulphide has, after titanium white, the second highest refractive index. Its chemical and thermal resistance is inferior to that of titanium dioxide. As a pigment it has a pure, white colour shade. It reflects UV radiation. The sphericity of the particles, as well as their low hardness of 3 Mohs, contribute to the low abrasivity of this pigment. Zinc sulphide is used in applications where low abrasivity and white colour shade are required. In paints, it contributes to their stability and good rheological properties. /3/

2.1.3 Lithopone

Lithopone is a mixture of $BaSO_4$ and ZnS. Zinc sulphide determines the pigmentary properties of the mixture, and that is why lithopone pigments are characterized by the quantity of ZnS present in the mixture. While the quantity of ZnS in commercial lithopones varies from 15 to 60%, the most common is a 30% lithopone pigment, containing 28-30% of ZnS and 70-72% of $BaSO_4$. /3/

Lithopone is mainly used in paints with a relatively high pigmentation, for example, filling and emulsion paints and primers of all kinds. In these areas, it is particularly characterized by its levelling properties, by low binder requirement and by giving paints good flowability. Lithopone is found to be very resistant to flocculation in all kinds of binder. Soft texture of lithopone makes it easy to formulate knifing fillers and primers. Lithopone is compatible with almost all binders. /4/

For economic reasons, it is often expedient to use lithopone together with TiO_2 pigments. This makes possible the superior hiding power of the TiO_2 pigments to be combined, at a reduced usage, with the economical and technical advantages of lithopone. /4/

2.2 Fillers

Fillers are substances in powder form that are practically insoluble in the medium in which they are applied. They are typically white or slightly coloured, and are used on meaning of their chemical or physical properties. The difference between filler and a pigment lies in the purpose for which it is used. Filler is not a colourant, it is employed to increase the bulk of a given material or modify the properties. /5/

White filler pigments have various functions, such as controlling gloss, texture, suspension, viscosity and hiding power enhancement. Fillers have low refractive indices. Common fillers are barium sulphate, calcium carbonate, kaolin, silica and silicates. /1/

2.2.1 Synthetic Barium Sulphate

Precipitated barium sulphate is also known as permanent white and blanc fixe. Barium sulphate ($BaSO_4$) is a fine, heavy, odourless, white powder of polymorphous crystals that have a rhombic structure. Precipitated barium sulphate finds a wide variety of uses in the coatings industry. The high filling power, low oil absorption, fineness and chemical inertness of barium sulphate are some of the properties that make possible it to be used as a filler for industrial and automotive primers. It is also used as an filler for wood paints and emulsion paints requiring a high level of gloss and a minimum distortion of colour. /6/

2.2.2 Calcium Carbonate

Precipitated calcium carbonate (PCC) is most generally used in paint as a filler for titanium dioxide. The small and narrowly distributed precipitated calcium carbonate particles help space the individual titanium dioxide particles and maximize their hiding power. This extension of the prime white pigment can improve opacity and reduce cost. /7/

Unlike ground calcium carbonates (GCCs), which come in just one shape regardless of size, precipitated calcium carbonates can be made in many shapes and smaller sizes not achievable by mere grinding. PCC, much like ground carbonate, finds its largest application in interior and exterior architectural coatings. /7/

2.2.3 Silica

Silica occurs generally in nature as sandstone, silica sand or quartzite. Silica is the starting material for the production of silicate glasses and ceramics. It is one of the most abundant oxide materials in the earth's crust. It can exist in a variety of crystalline forms or in an amorphous form. Its grindability to specific particle size distributions facilitates its use as a filler material to bulk out products. Silica is generally used as a filler in paints, plastics, rubber, adhesives and putty. /8/

2.2.4 Silicates

Minerals which combine oxygen and silicon, are called silicates. The silicates can be organized in terms of their crystal structures and chemical compositions (Table 1). /9/

Table 1. Silicates. /9/

Mineral		**Idealized Formula**	**Cleavage**
Olivine		$(Mg,Fe)_2SiO_4$	None
Pyroxene group (Augite)		$(Mg,Fe)SiO_3$	Two planes at right angles
Amphibole group (Hornblende)		$Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°
Micas	Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane
	Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	
Feldspars	Orthoclase	$KAlSi_3O_8$	Two planes at 90°
	Plagioclase	$(Ca,Na)AlSi_3O_8$	
Quartz		SiO_2	None

2.2.5 Kaolin

The term kaolin is used to describe a group of hydrous aluminum silicates of which kaolinite is the dominating mineral. Chemical formula of kaolin is Al_2O_3• 2 SiO_2 • 2 H_2O. When kaolin is broken down, it will show approximately 45% SiO_2 and 37% Al_2O_3 with trace impurities of TiO_2, Fe_2O_3, quartz, and mica. Kaolin is white and chemically inert silicate mainly composed of very fine particles. /10/

Individual kaolins vary in many physical aspects, which in turn influence their end use. Kaolin is commercially interesting because of its degree of crystallinity which influences the brightness, whiteness, film strength, opacity, gloss and viscosity. /11/

In its hydrous or calcined forms, kaolin can improve the optical, mechanical and rheological properties of a paint. Calcined kaolins are widely used in matt and satin paints where they can fulfil increased opacity, whiteness and scrub resistance. It is advantageous to use kaolin as partial replacement for TiO_2 pigment. /11/

2.3 Binders

All paints have a necessary component, a vehicle which is a binding agent. It both binds the pigment particles together before use, and once applied (and the liquid component has evaporated) has a solid component which remains behind both binding the pigment particles together and also binding the film of color to a surface. /12/

Binders contain synthetic or natural resins such as acrylics, polyurethanes, polyesters, melamine resins, epoxy, or oils /12/. The binder is a very important ingredient that affects almost all properties of the coating as adhesion and related properties like resistance to blistering, cracking and peeling. Other key resistance properties like resistance to scrubbing, chalking and fading as well as application properties, like flow, levelling and film build, and gloss development are also properties to which binder affects. /13/

2.4 Additives

A fractional part of paint, 0,1-1 % of weight, is additives that improve paints properties. Those chemicals are also necessary when paint coating is forming. Additives can be divided to groups according to their effect. They can be for example antifoaming and anti-skinning agents, anti-corrosive pigment enhancers, anti-settling agents and driers. /14/

2.5 Solvents

Solvent is important part of paint and the term solvent is used to contain liquids that don’t dissolve binder. Solvents are used in paint compositions for two main purposes. They enable the paint to be made, and they enable it to be applied to surfaces. /15/ If incorrect solvent is used, paint precipitates and becomes useless /14/.

In water-based systems the water may operate as a true solvent for some components, but be a non-solvent for the main film former. This is the case in decorative emulsion paints. In most cases it is common to refer to the “aqueous phase” of the composition, acknowledging that the present water, although not a solvent for the film former, is present as the major component of the liquid-dispersing phase. A wide range of organic liquids are used as paint solvents, the type of solvent depending on the nature of the film former. /15/

Solvency alone is not the only criterion upon which solvent is chosen. Other important factors contain evaporation rate, toxicity, flammability, and cost. These factors suppose different degrees of importance depending on how the paint is used. If the paint is applied under conditions of industrial manufacturing, it is probable that problems related to odour, flammability and toxicity have to be under control. /15/

3 MANUFACTURE OF TITANIUM DIOXIDE

Titanium dioxide pigments are produced with two different kind of processes, namely the sulphate process and the chloride process. /16/

3.1 Sulphate Process

The sulphate process is said to utilize all the processes of classical chemistry, except distillation, and is a complex multistage industrial operation. In the sulphate process (Fig. 2), the titanium-bearing ore called ilmenite is reacted with sulphuric acid with consequent hydrolysis of the resultant titanyl sulphate yielding a hydrated oxide. Then it is calcined in a rotary kiln at a temperature of approximately 1000 ºC to produce pigmentary titanium dioxide. The sulphate process can be depicted with the following reactions /2/:

$$FeOTiO_2 + 2\ H_2SO_4 \rightarrow TiOSO_4 + FeSO_4 + 2\ H_2O \quad (1)$$

$$TiOSO_4 + 2\ H_2O \rightarrow TiO(OH)_2 + H_2SO_4 \quad (2)$$

$$TiO(OH)_2 \rightarrow TiO_2 + H_2O \quad (3)$$

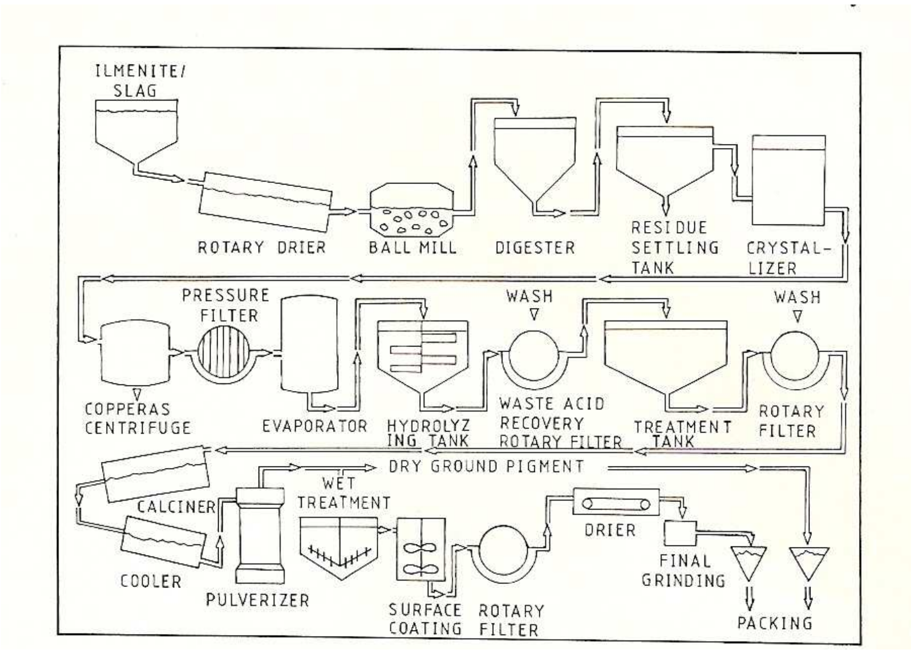

Figure 2. The sulphate process. /2/

3.2 Chloride Process

The chloride process (Fig. 3) is just for rutile titanium dioxide production. In this process, mineral rutile or refined ore is reacted with gaseous chloride in the coke’s presence, forming liquid titanium tetrachloride. After distilling, this is oxidized in the vapour phase, to produce pigmentary titanium dioxide. The chloride process can be depicted with the following reactions /2/:

$$TiO_2 + C + 2\ Cl_2 \rightarrow TiCl_4 + CO_2 \qquad (4)$$

$$TiCl_4 + O_2 \rightarrow TiO_2 + 2\ Cl_2 \qquad (5)$$

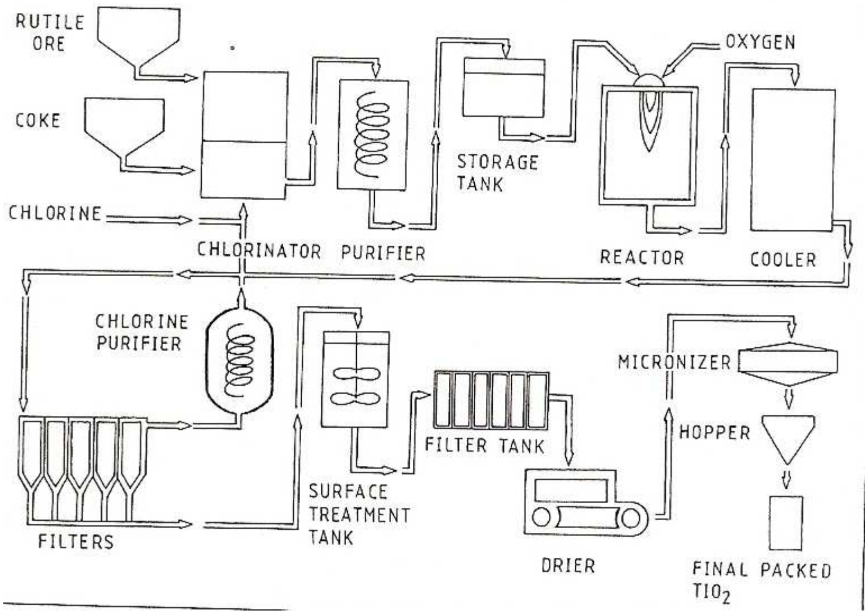

Figure 3. The chloride process. /2/

3.3 Surface Treatment of Titanium Dioxide Pigments

A range of surface treatments are usually applied to the base pigment, regardless of its original manufacturing route, to obtain the balance of properties required /2/. The surface properties of pigment particles are largely determined at the surface treatment step of the production process, where the surface of pigment particles is modified with various inorganic and organic compounds. Most commonly, the particles are first coated with inorganic compounds and, as a final touch, an organic compound is added onto the surface to improve dispersibility. The differences between pigment grades manufactured for different purposes often lie in different surface treatment variables including the chemicals used, the quantities of each, and the coating process itself. /16/

4 MANUFACTURE OF FILLERS

4.1 General Aspects

Fillers are inorganic pigments and they are got from minerals. There exists two manufacturing methods of fillers. In one method, mined mineral is milled with or without water. After that it is screened, dried and packed. Another method is chemical precipitation. Raw material for milled and screened filler should be pure, whereas that for chemical precipitation can be contaminated. /14/

4.2 Manufacture of Barium Sulphate

Natural barium sulphates are processed by using grinding method /17/. Precipitated barium sulphate can be produced either directly from the reduction of barite or it can be obtained indirectly as a by-product in the manufacture of lithopone (Fig. 4). In either case, the process begins with the formation of a barium sulphide melt which is obtained by the reduction of natural barite with coal in a rotary kiln at 1200-1300 °C according to the reactions /6/:

$$BaSO_4 + 2\ C \rightarrow BaS + 2\ CO_2 \qquad (6)$$

$$BaSO_4 + 4\ C \rightarrow BaS + 4\ CO \qquad (7)$$

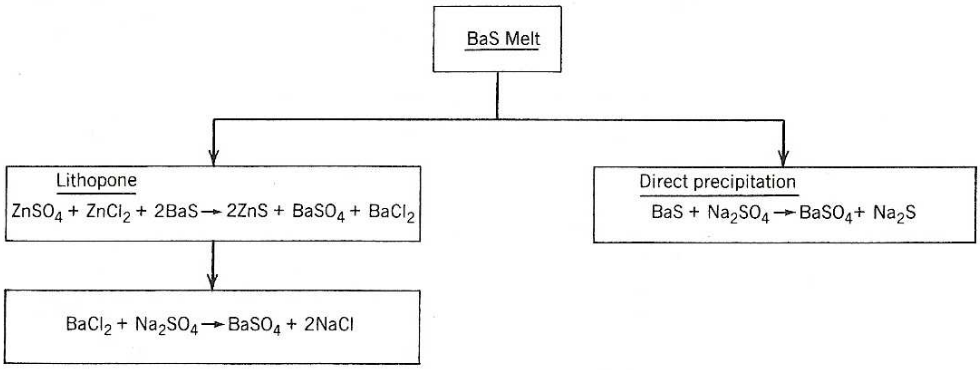

Figure 4. Production of precipitated barium sulphate. /6/

This white-hot reaction product is cooled down in water and the barium sulphide is extracted by countercurrent leaching with hot water. The resulting solution is filtered and pumped into large vats equipped with stirrers. The impurities remain behind as a mud containing the gangue and insoluble sulphides. /6/

The direct production of precipitated barium sulphate is accomplished by adding a solution of sodium sulphate to the vat according to the reaction

$$BaS + Na_2SO_4 \rightarrow BaSO_4 + NaS \qquad (8)$$

The precipitated barium sulphate is then separated from the solution, dried, and ground to give the high-grade blanc fixe powder used as a pigment filler and inert filler. /6/

The precipitated barium sulphate obtained as a by-product of lithopone production occurs as a result of the production of the high-strength lithopones. For the production of 30% strength lithopone, 1 mole of sodium sulphate is used with 1 mole of zinc chloride in the reaction

$$ZnCl_2 + Na_2SO_4 + BaS \rightarrow ZnS + BaSO_4 + 2\ NaCl \qquad (9)$$

For lithopones of greater than 30% strength, the reaction components are no longer equimolar and the resulting reaction occurs:

$$2\ ZnCl_2 + Na_2SO_4 + 2\ BaS \rightarrow 2\ ZnS + BaSO_4 + BaCl_2 + 2\ NaCl \qquad (10)$$

or

$$ZnSO_4 + ZnCl_2 + 2\ BaS \rightarrow 2\ ZnS + BaSO_4 + BaCl_2 \qquad (11)$$

A blanc fixe paste is obtained from the resulting barium chloride solution in a second precipitation reaction according to the reaction /6/:

$$BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2\ NaCl \qquad (12)$$

4.3 Manufacture of Kaolin

When the crude kaolin is mined, it is ready for processing. There are two general manufacturing methods, the air-float process and the water-wash process. Air flotation is generally used when filler clays are manufactured, whereas the water-wash process is used for both filler and coating clays. /10/

In the air-float process, the crude kaolin is crushed. After that it is dried first in cage mills and then dried completely in roller mills. When the desired particle size is achieved, the product is floated from the roller mill on a stream of air through a whizzer separator. The fine particles pass through and are set for operation or extra milling and the impurities and rough particles are removed. /10/

Water-wash process (Fig. 5) is more complicated than air-floated process. First kaolin is worked with high-shear machinery. Addition of water and chemical is followed with preparation of a water suspension that has trace impurities removed. This suspension is next separated by centrifuges into the desired particle size. The coarse particles are delaminated with mechanically shearing the agglomerates with extruders or attrition mills. /10/

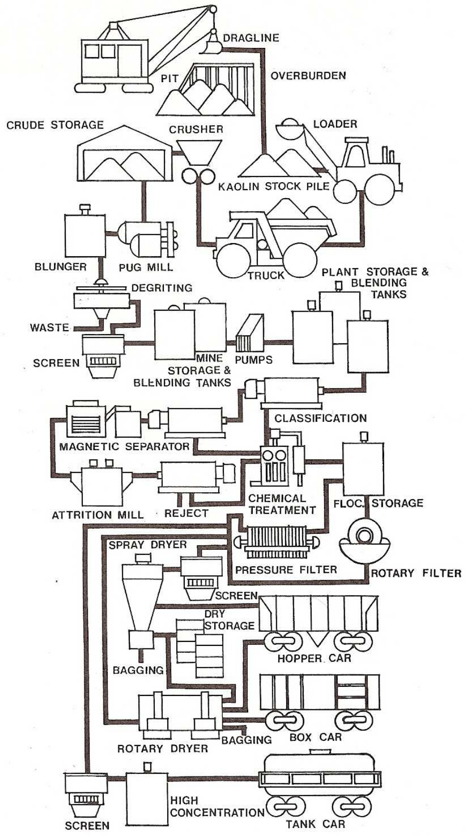

Figure 5. Schematic representation of a typical waterwash processing facility. /10/

Chemical leaching and magnetic separation both improves brightness and colour. After this, most of the water and earlier added chemicals are then removed with rotary vacuum filters or pressure filters. /10/

5 MANUFACTURE OF PAINTS

The manufacture of paint involves the following stages: mixing, grinding, thinning, adjusting, and filling. /1/

One of the older methods consisted of mixing all the pigment and part of the vehicle to make a paste of suitable consistency in a tub with rotating blades. This paste was then fed by means of a trough into a slow-speed stong mill which had two circular stones, one stationary and the other rotating above it. Next, this paste was fed in a continuous stream into a thinning tank, which had rotating blades. At this point the remainder of the liquids was added, and the completed product was tested for viscosity, colour, and other physical properties pertinent to the prepared formulation. The approved batches, were then strained and filled into appropriate size containers. /1/

Dispersion by old-fashioned low-speed stone mills is extremely slow, costly and obsolete. Various types of more efficient equipment are now in use. The general principle, however, is the same. That is to wet each individual particle thoroughly with the vehicle and to eliminate flocculated aggregates. /1/

Nowadays manufacture of a paint consists of premixing, dispersing, after-mixing and toning stages. /14/

Various semi-finished products of some raw materials are often prepared before real manufacturing process. It is important to add raw materials in right order so that the manufacture process succeeds. Right way of addition is also vital. Purpose of premixing is to prepare suitable grinding part before dispersing. /14/

In powder form, pigment particles join together as agglomerates. Purpose of dispersing is to disperse these agglomerates and wet surface of pigment particles with binder. In addition, this way formed dispersion should be stabilized which means that it should remain fine-grained for a long time. Dispersing can be done with flash mixer, ball mill or three-roll mill. In flash mixer, there is a propeller assembled to vertical axis. In ball mills, there is a horizontal rotary drum where steel balls or porcelain balls grind pigments. In three-roll mills, dispersing happens between rotary rollers. /14/

In after-mixing, rest of the raw materials are added to dispersed grinding batch. Mixing is done with propeller mixer or flash mixer. It is important that addition is made properly and that mixing is powerful enough. At the stage of toning, the paint is tinted with special tinting pastes. Tint is tended to get near standard, tint of colour chart, that is set down. /14/

6 MOST IMPORTANT PROPERTIES OF WHITE PIGMENTS IN PAINTS

In any pigmented system, the achieved degree of pigment dispersion will have a profound effect on the properties of the system. In relative terms, titanium dioxide pigments are easily dispersible. As a result of surface treatment of TiO_2 pigment, those can be processed using a wide variability of modern machinery, required that correct millbase formulating procedures have been followed. /2/

In any paint system, no matter how accurately the milling process has been carried out, there exist pigment particles of various sizes. It has been assessed that even in a well-milled paint only 20-25% of titanium dioxide pigment is present as single crystals, the remaining part being present as groups of two or more individual crystals. These particle groups are usually formed by the process of flocculation. The presence of flocculation in a system is the result of instability. It is always present to a degree and thus, it is essential that it is minimized to obtain acceptable optical properties for the system. Although flocculates are loose assemblies of particles and they can easily be broken down, but also readily formed. /2/

When the state of dispersion is good, the stability of viscosity is also good. Viscosity is the quantity that describes resistance of a fluid to flow. The higher is viscosity of paint, the thicker and less fluid it feels. Viscosity of paint depends on dispersal properties of a pigment. /14/

7 MOST IMPORTANT PROPERTIES OF WHITE PIGMENTS IN PAINT COATINGS

7.1 Opacity

The most important property of any white pigment is its ability to opacity and bleach the medium in which it is dispersed. The opacifying potential of titanium dioxide or other white pigments, is essentially controlled by two properties— particle size and refractive index. The refractive index of a material is an essential property associated with crystal structure of the material and thus the pigment manufacturer has no control over this particular parameter. A paint film is opaque because particles of pigment scatter and/ or absorb light, thus preventing light to reach the substrate. Incident light can interact with a pigmented paint film in various ways (Fig. 6). /2/

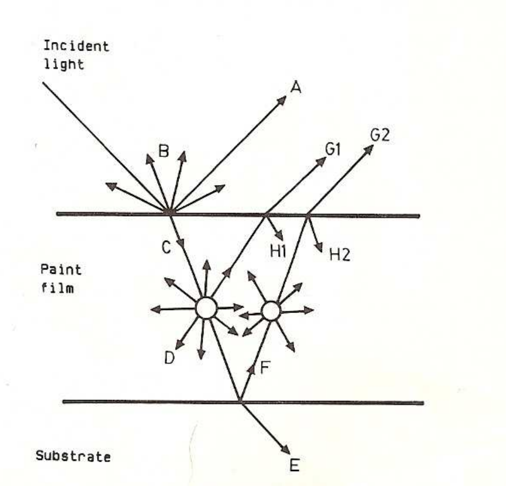

Figure 6. Interaction of light with a pigmented paint film. /2/

At the film surface, light is reflected (A) according to law of reflection. The reflection degree depends on the refractive index of the film. If the surface is optically smooth, the angle of reflection is equal to the angle of incidence, but more commonly with pigmented systems there is some diffusion (B) from the surface itself. The remainder of the incident light (C) passes into the film where it can be scattered (D), absorbed by pigment particles, or absorbed by the resin. These interactions determine the colour and intensity of light (G1) that re-emerges from the film surface. /2/

In films that are not opaque, some of the light reaches the substrate, where it may be absorbed (E) or reflected (F). Again, some of this reflected light may finally reach the film surface (G2). Not all the light reaching the film surface emerges. Some is internally reflected (H1 and H2) and may be further scattered and absorbed by pigment particles within the film. /2/

The combination of all these effects leads to the phenomenon of opacity. Thus, white paints opacity is mainly caused by scattering light, while in colored paints there is an increasing dependence on absorption as the concentration of colored pigment increases. /2/

Most of the light that enters a paint film is reflected and refracted many times before either escaping from the surface of the film, as reflected light, or being absorbed by the substrate. In a system containing a low refractive index pigment, light is deflected through a relatively small angle when it strikes an individual particle and thus light has a high probability of reaching the substrate (Fig. 7). Thus an efficient pigment particle should scatter light through as large angle as possible. /2/

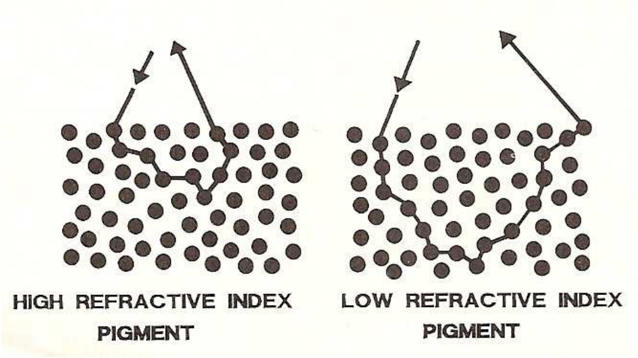

Figure 7. Reflection of light from both high and low refractive index pigments. /2/

7.2 Degrees of Coloration

Two aspects of colour, whiteness and undertone, are important to the users of titanium dioxide pigments. White pigment itself causes the whiteness and products that contains mixture of white and coloured pigments causes undertone. /2/

Whiteness is developed by careful purification of the pigment during the manufacturing process. It is particularly important to reduce to a minimum the concentration of contaminant elements which have coloured oxides. Another significant factor for development of whiteness is the particle size of the pigment. The ratio of scattering increases as the crystal diameter approaches half of the wavelength of light. When the ratio of scattering to absorption increases, it produces a substantial increase in reflectance. /2/

Undertone is a term more commonly applied to coloured pigments. It is defined as the colour obtained when such a pigment is entirely extended with white. Undertone of white pigment may be described as the hue (brownish or bluish) of a grey paint containing the pigment in admixture with a standard black pigment. Undertone is mostly dependent on the particle size of the titanium dioxide pigment and can thus be controlled by the manufacturer. In general, pigments with small particle sizes have blue undertone while larger particle materials have brown undertone. Undertone is also affected by the state of dispersion of a pigment, becoming more blue when dispersion improves. /2/

7.3 Gloss

Gloss can be observed as a sensation when observer experiences it when light is reflected from a surface and thus, to a degree, it is a relative effect. Gloss is an important parameter in many surface coatings and it can be influenced by the distribution and concentration of titanium dioxide pigments in the paint film. If paint films are optically smooth, their specular gloss would be directly related to the refractive index of the film surface. Despite, paint films normally have a degree of surface roughness, related to the flow of the film and to the presence of pigment in the system. The surface roughness of a paint film can be considered to consist of two components, macroroughness, and microroughness. It is primarily microroughness that is affected by the presence of titanium dioxide pigment particles at, or near, the surface of the paint. /2/

The primary reason for incorporating titanium dioxide pigment in paint films is to produce opacity. Increasing the level of pigmentation to achieve high opacity also causes the observed gloss to fall. Although theory predicts that increasing the refractive index of a paint film will increase the observed gloss value. That is not the case in paint systems where the refractive index increase has been achieved by increased pigmentation levels. This is simply because the presence of pigment particles near the surface of the film causes a marked increase in surface microroughness and thus a decrease in the observed gloss. /2/

Since the surface roughness of a coating system is notably affected by the degree of pigment dispersion, for a given pigment loading, it has a significant effect on gloss levels in most systems. Also, the presence of flocculation in a paint system results in a growth in the mean particle size of the pigment and hence a growth in surface roughness and a decrease in gloss. /2/

7.4 Durability

It is well proved that pigmented coatings subjected to weathering undergo oxidative destruction due to incident ultraviolet radiation in the presence of oxygen and water. This results in a progressive loss of gloss, mass loss, and chalking. Two degradation mechanisms are responsible for the breakdown of the polymer in a pigmented coating system. These are direct photochemical degradation of the polymer by ultraviolet radiation and photocatalytic degradation induced by titanium dioxide. /2/

8 MOST IMPORTANT PROPERTIES OF FILLERS IN PAINT COATINGS

Fillers are cheap materials in comparison to pigments. Because of this, they may be used in association with prime pigments to achieve an exact type of paint. It is technically difficult and prohibitively expensive to manufacture paint that consists of only titanium dioxide. It is more economic to use rough particle fillers, like barium sulphate or calcium carbonate along with titanium dioxide to achieve opacity and whiteness. Fillers don’t impact on colour and in most cases it is important that they are colourless. /15/

Particle size of fillers is more small-sized than that of titanium dioxide. This enables fillers to be used in high-quality top coats possessing a high level of gloss. /6/

Dispersibility is a characteristic of a material divided evenly in another substance. It relies on the number and strength of the binding sites between the agglomerates and also on the wettability of the dispersed material. The colour development rate and reduction in granularity can operate as a measurement of dispersibility. Dispersion is determined when smaller particles build up from powder agglomerates in a medium and when medium’s particles wet concurrently. /18/

Grinding produces crystal fracture surfaces and then interfacial activity of filler grows. Thereafter surface of filler particles bears hydroxyl groups. The fillers are commonly hydrophilous. That is why these fillers don’t wet very well or if so, they wet faintly, by aliphatic hydrocarbon solvents. Binder attends on this function with surface-active agents and wetting agents. Wetting of agglomerates plays a major role in the dispersion. Dispersion should remain stable over a protracted period and flocculation is unwanted. /18/

EXPERIMENTAL PART

9 PURPOSE OF THE WORK

Purpose of the work was to study the changes in viscosity of paint and in optical properties of paint film when titanium dioxide pigment is partly replaced with filler. In addition, effect of mixture of titanium dioxide and kaolin on characters of paint film was also examined.

10 EXPERIMENTAL

10.1 Paint Formulations

White and grey solvent borne (10.1.1) and water-borne paints (10.1.2) were prepared according to standard recipies of Sachtleben Pigments.

10.1.1 Solvent Borne Paint

Instruction of white solvent borne paint is KP-MM-589.
Instruction of grey solvent borne paint is KP-MM-227.
240 ml glass jar, ø 70 mm, h 90 mm
130 g glass balls, ø 8 mm

8,6 g Synolac 60 W (70%)
5,2 g Shellsol A
5,9 g White Spirit
0,5 g 75 % Colorol
0,1 g Exkin 2
30,0 g TiO_2 (P:B = 5:1)

Dispersing in ball mill (2 h).

Stabilization
8,6 g Synolac 60W (70%) (P:B = 2,5:1)

Mixing in ball mill 30 minutes.

Tinting (if wanted)
7,50 g Black Dreibrandruss- tinting paste TSL-VO-03.
Contains black pigment 0,24 g/ 5g.
Mixing in ball mill 30 minutes.

Completed paint
25,7 g Synolac 60W (70%)
0,1 g Co 10 HEX-CEM
0,3 g Zr 12 HEX-CEM
0,5 g Ca 10 CEM-ALL

85,5 g in total (P:B = 1:1)

Mixing in ball mill 30 minutes.

Volume of white solvent borne paint: normal = 71 ml
Volume of grey solvent borne paint: normal = 74 ml
Density of paint = 1,3 kg/ dm^3

10.1.2 Water-borne paint

Instruction KP-MM-562.

Dispersion

Dispermat FT1 high speed dissolver, propeller 40 mm.

Grinding container: 250 ml steel decanter, height 80 mm, ø 58 mm.

Dispersing solution:

Following raw materials are added to grinding container in given order and are agitated to smooth mixture.

25,1 g	propylene glycol
2,0 g	Orotan 1124
0,5 g	25 % ammonia
0,4 g	Kathon LXE

28,0 g	

Mill base grinding:

28,0 g	dispersing solution
3,0 g	Tegofoamex 1488/ H_2O 1:1
98,2 g	TiO_2 pigment

Notice: Tegofoamex and water are agitated together (ratio 1:1) before the mixture is added to dispersion solution.

Grinding 3500 rpm, 8 minutes.

Stabilization:

These are added to mill base mixture:

40,8 g	Acrysol RM-55/ H_2O 1:2	(pH 8,5-9,0)
6,4 g	H_2O	

Agitation to smooth mixture.

Completed paint

To 360 ml glass jar is weigh
105,8 g dispersion

To which the following agents are added when dissolver is rotating:
170,3 g Primal HG-74D
7,4 g Methoxybutanol
10,9 g Texanol
6,0 g H_2O
0,6 g Tegofoamex 1488 (P:B = 0,8:1, PVC = 18,8 %)

Tinting

50,00 g Completed paint
2,50 g Tinting paste TSL-VO-5

10.2 Application of paint films

Parallel films of different paints were applied on Leneta 2A cards to be able to compare visually the colour of paint films with each other.

10.2.1 Solvent Borne Paint

Two films of white solvent borne paint were applied on black and white Leneta 2A cards. First paint film was applied with 90 µm applicator. Two cards were applied per sample. Paint films were applied by using automatic Erichsen applicator (speed of applique 40 mm/s). Then cards of first paint film were let to dry.

Another paint film was applied with the 200 µm applicator onto the first paint film (90 µm) and just onto second card of every sample. Paint films were let to dry.

Paint films of grey solvent borne paints were applied with a 100 µm applicator.

10.2.2 Water-borne Paint

First films of white water-borne paints were applied with 120 µm applicator and another paint films with 200 µm applicator.

Paint film of grey water-borne paint was applied with 120 µm applicator.

10.3 Performance Testing of Paints and Paint Films

10.3.1 Viscosity

Viscosity of all white paints was followed up for two months. Viscosity was measured 1, 7, 14 and in some cases 30 and 60 days after date of the paint preparation. Measurements were made from paints at room temperature. Viscosities of paints were measured with Brookfield Model DV-II+ Viscometer. In addition, viscosities of solvent borne paints were measured with Brookfield KU-2 Viscometer.

10.3.2 Colour

Brightness and tone were measured from pigmented paint film with HunterLab UltraScan XE chromometer. While defining colour characteristics, intensity of light is measured when it reflects back from pigmented paint film in different wavelengths of visible light. The brighter is pigment, more it reflects back light.

From L*, a* and b* values, L* describes brightness of a pigment as proportional value in scale 0…100. Value 100 corresponds to ideal white and value 0 corresponds to black coat. a* describes colour shade in direction of red and green. Value of +a means red tone and –a means a green tone whereas +b means yellow colour tone and –b means blue tone.

Degree of colouration was assessed with HunterLab UltraScan XE. Measurements were performed for both white and grey water and solvent borne paints.

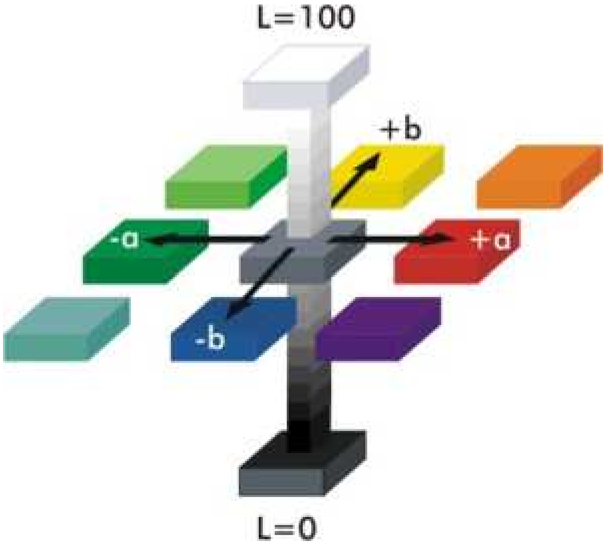

Figure 8. Colour system picture. /19/

Tint reducing power and undertone are studied from a paint tinted to some colour, often to grey with black paste. Tint reducing power of titanium dioxide means capability of pigment to whiten black or pigmented mixture. When the colour of paint diverges to blue or brown direction from the standard, it expresses the undertone.

10.3.3 Gloss

Gloss is determined by measuring specular reflection of incident light coming in particular angle from the pigmented paint film. In this study, specular reflection of incident light from the paint film was measured in angles of 20º and 60º with the Erichsen Picogloss 503.

10.3.4 Grammage and Scattering Coefficient

Measurement method is based on utilization of gamma radiation. Gamma radiation traverses measured product. Remnant radiation that comes to detector is a measure for the density of measured product.

$$I = I_o \cdot e^{-\mu \cdot \rho \cdot d} \tag{1}$$

where:

I= Radiation that comes to detector
I_o= Continuous radiation
μ= Absorption coefficient
ρ= Density of absorbent
d= Thickness of absorbent

Intensity of radiation that comes to detector, depends on the distance between the source and the detector. /20/

Grammages of paint films were measured with the help of hiding power programme and with Berthold LB 386-20C radiometric densitometer. Programme takes into account grammages measured before from blank cards. Colour was also measured with the hiding power programme and it was measured from first card of every sample.

Reflectance of light was measured from black part of the first paint film (R_0) and from white part of the second paint film (R_∞). By means of R_0 and R_∞, scattering coefficient S is obtained. These are measured with the help of Autoelrepho Terminal Color Meter.

10.4 Effect of Barium Sulphate Filler Concentration on Paint Properties

In this series, titanium dioxide grades Sachtleben RDI-S and Hombitan R611 and filler grade Sachtleben Micro (synthetic barium sulphate) were studied in solvent and water-borne paint formulations (10.1). Product properties are represented in appendix 1 (Table 1 and 2). 0 to 30 % (in 5 % steps) of titanium dioxide was replaced with filler in paint formulation (Table 2).

Table 2. Pigment filler ratio as weight percent.

TiO_2 pigment (w-%)	$BaSO_4$ filler (w-%)
100	0
95	5
90	10
85	15
80	20
75	25
70	30

10.5 Effect of Titanium Dioxide Grade on Paint Properties

In this series, five different titanium dioxide grades and one filler were studied in solvent and water-borne paints. Filler was Sachtleben Micro (synthetic barium sulphate) and titanium dioxide grades were Sachtleben RDI-S, Sachtleben 660, Sachtleben RD3, Hombitan R210 and Hombitan R611. Product properties are represented in appendix 1 (Table 1 and 2). 0, 10, 20 and 30 weight percent of titanium dioxide was replaced by filler in paint formulation (Table 3).

Table 3. Pigment-filler ratio as weight percent.

TiO_2 pigment (w-%)	$BaSO_4$ filler (w-%)
100	0
90	10
80	20
70	30

10.6 Comparison of Performance of Mechanical Mixtures of Filler and TiO_2 to Performance of Sachtleben K40 in Paints

Performance of mechanical mixtures of titanium dioxide and barium sulphate as well as mixtures of titanium dioxide and kaolin were studied in both solvent and water-borne paints. Performance was compared to that of Sachtleben K40 which is after-treated mixture of TiO_2 (60%) and kaolin (40%). Mechanical mixtures contained 60% titanium dioxide pigment and 40% filler (Table 4). Product properties are represented in appendix 1 (Table 1 and 2).

Table 4. Studied pigments and fillers and their ratio as weight percent.

Pigment (w-%)	Filler (w-%)
60% Sachtleben RDI-S	40% Sachtleben Micro
60% Sachtleben RDI-S	40% Amazon Premium
60% Hombitan R210	40% Sachtleben Micro
60% Hombitan R210	40% Amazon Premium
100% Sachtleben K40	-

11 RESULTS

11.1 Effect of Barium Sulphate Filler Concentration on Paint Properties

In grinding process when paints were prepared, all paints of Sachtleben RDI-S got wet better than those with Hombitan R611 (Appendix 4: Table 1).

In the course of time viscosities grow (Fig. 9, 10 and Appendix 2: Fig. 1). When filler content of the paint increases, viscosity of the paint decreases. Variations in viscosity of white solvent paint are quite insignificant (Fig. 10).

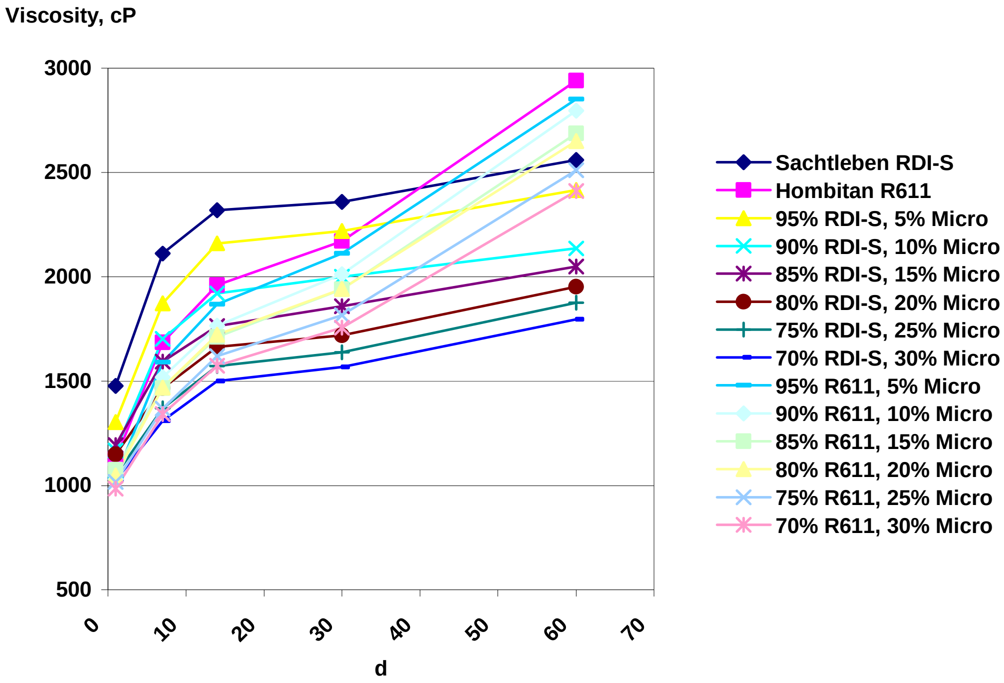

Figure 9. Viscosity of white water-borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

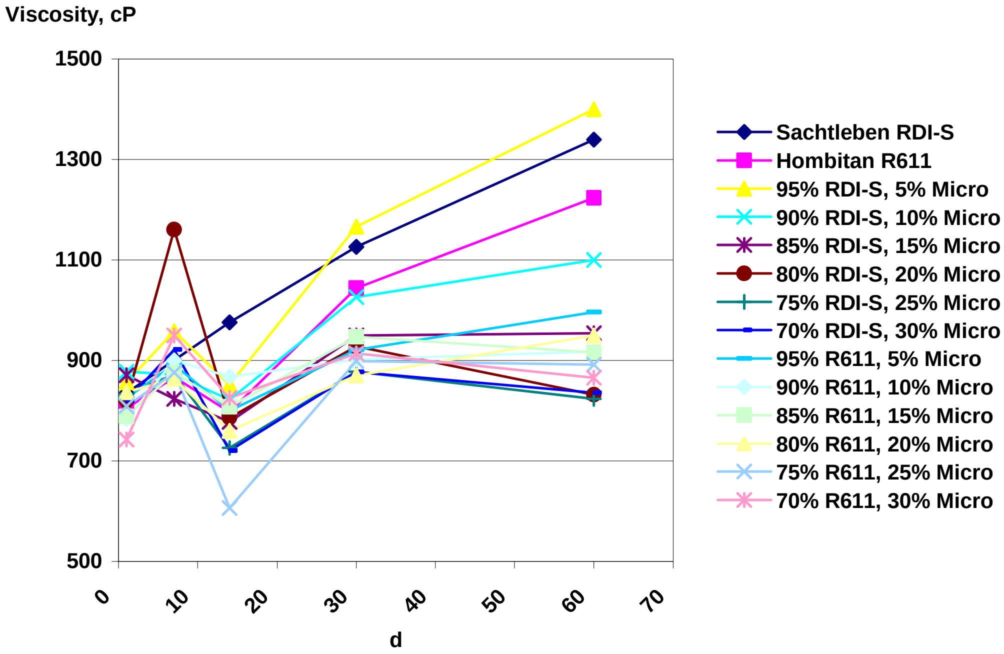

Figure 10. Viscosity of white solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

Gloss of paint films increase when filler content increases (Fig. 11 and 12).

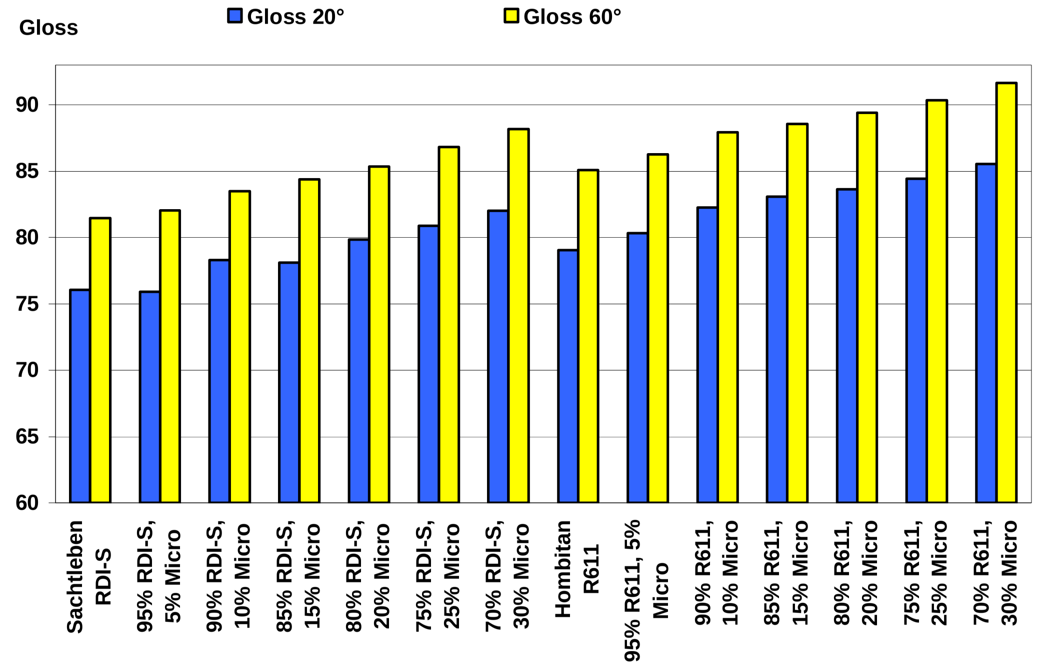

Figure 11. 20° and 60° gloss of white solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

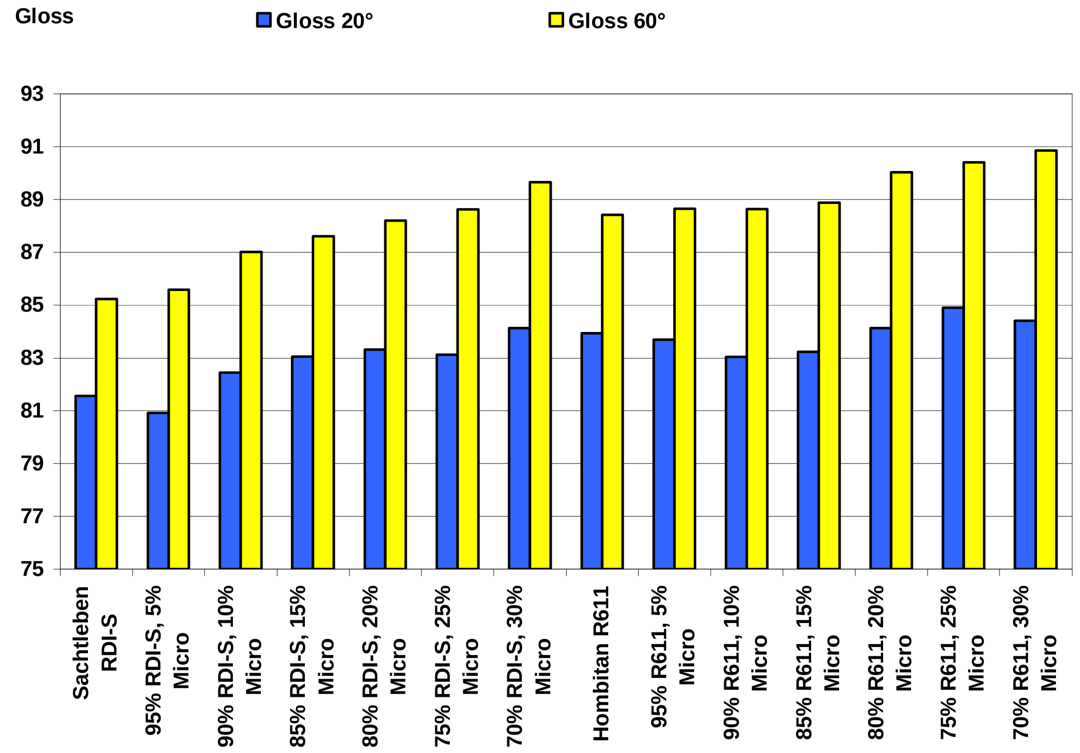

Figure 12. 20° and 60° gloss of grey solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

In water-borne paints (Fig. 13), glosses decrease when filler content increases. Titanium dioxide and filler interact less with water-borne paint.

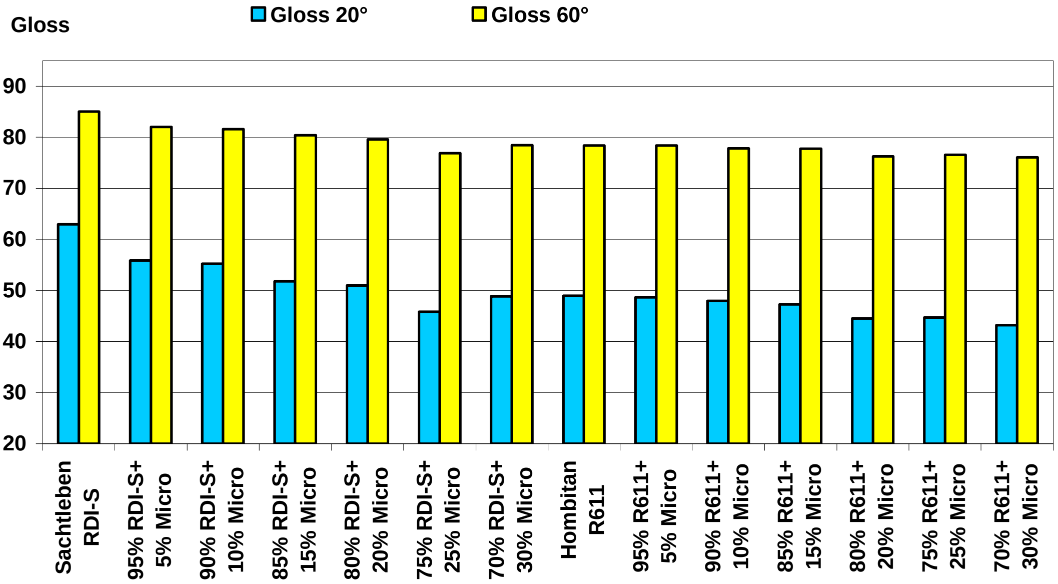

Figure 13. 20º and 60º gloss of white water-borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

Whiteness decreases when filler content increases (Fig. 14, Appendix 2: Fig. 2, Appendix 2: Fig. 3 and Appendix 4: Fig. 1). Difference of 0,5 unit in whiteness is significant and difference between Sachtleben RDI-S and 70% Sachtleben RDI-S + 30% Sachtleben Micro is minor than those with Hombitan R611.

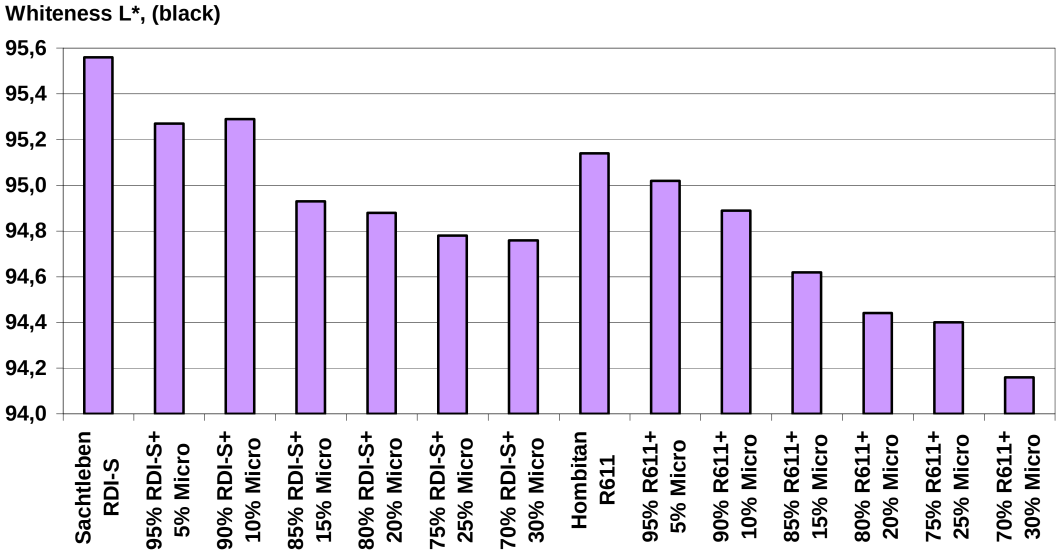

Figure 14. Whiteness L* of white water-borne paint on black backing with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

When filler content of the paint increases, tint reducing power L* decreases (Fig. 15 and 16, Appendix 3: Fig. 1 and Appendix 4: Fig. 4). Variations between Sachtleben RDI-S and 70 % Sachtleben RDI-S+ 30 % Sachtleben Micro are significant as well as variations between those with Hombitan R611 (Fig. 15 and 16).

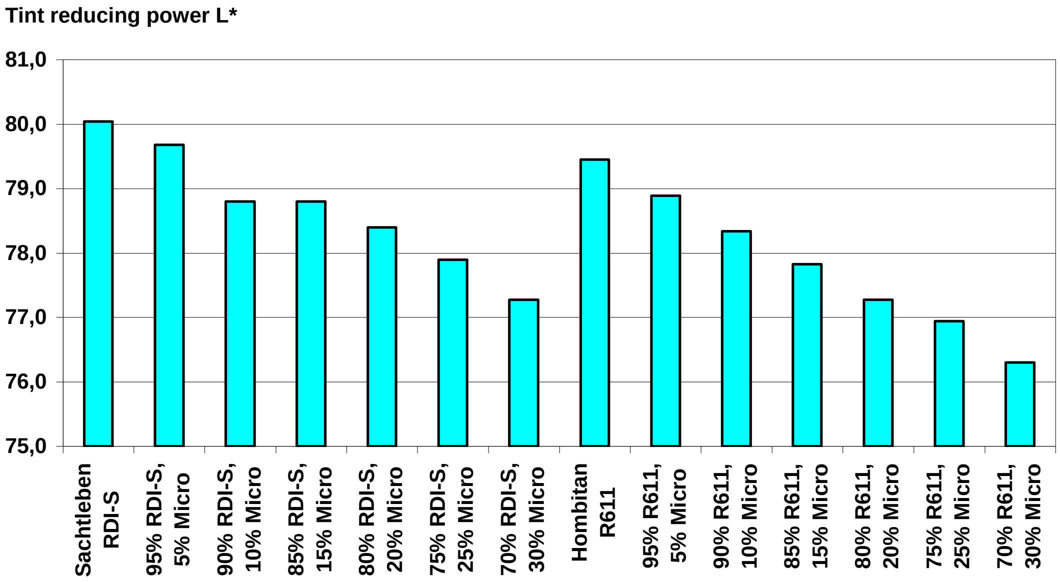

Figure 15. Tint reducing power L* of grey solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

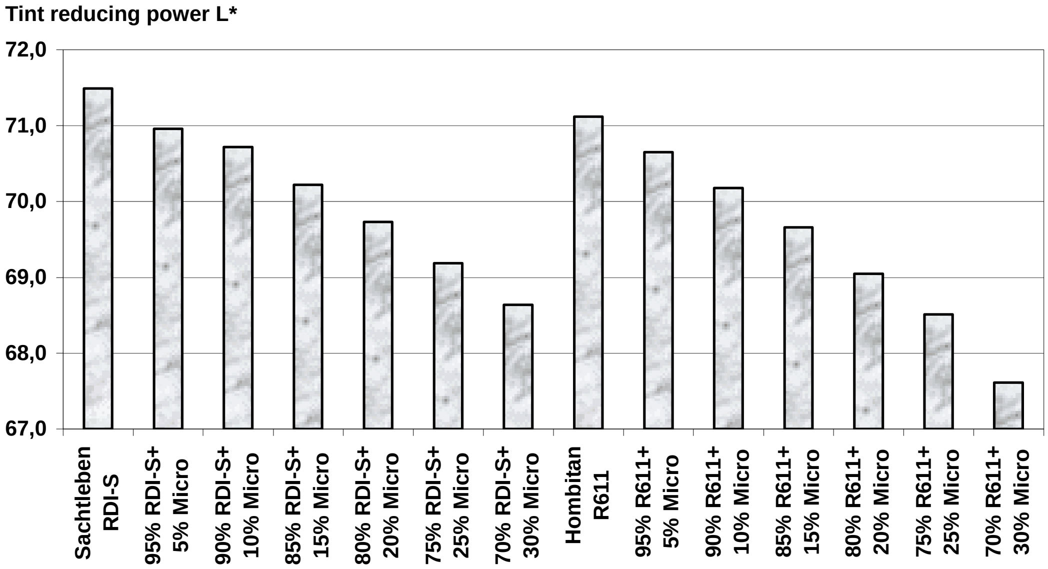

Figure 16. Tint reducing power L* of grey water-borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

Increase of filler content didn’t have an effect on tone and undertone of the paint and noticeable variation is normal (Fig. 17,18, 19 and 20, Appendix 2: Fig. 4, Appendix 3: Fig. 2 and Appendix 4: Fig. 2).

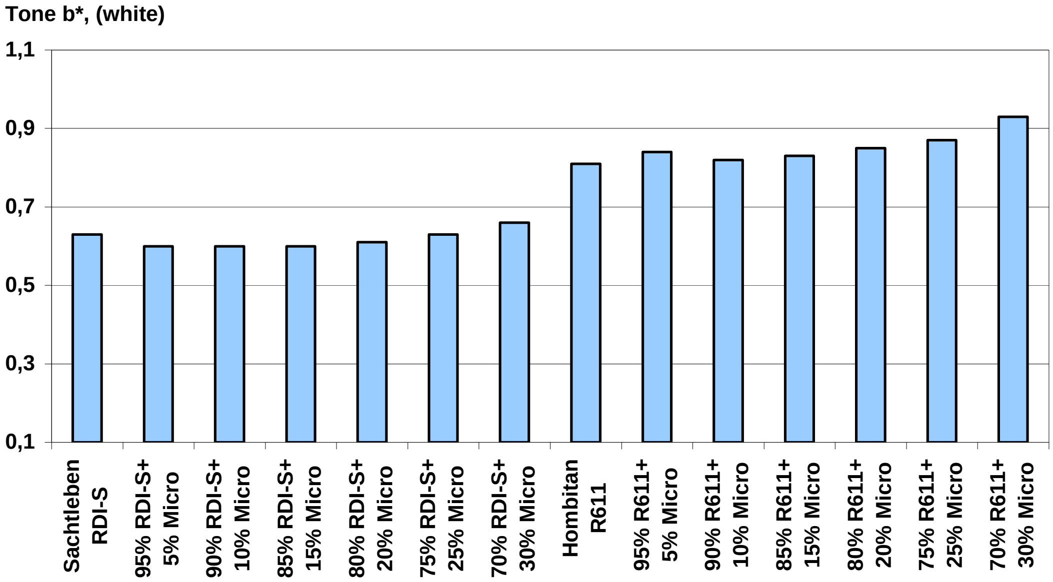

Figure 17. Tone b* of white water-borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

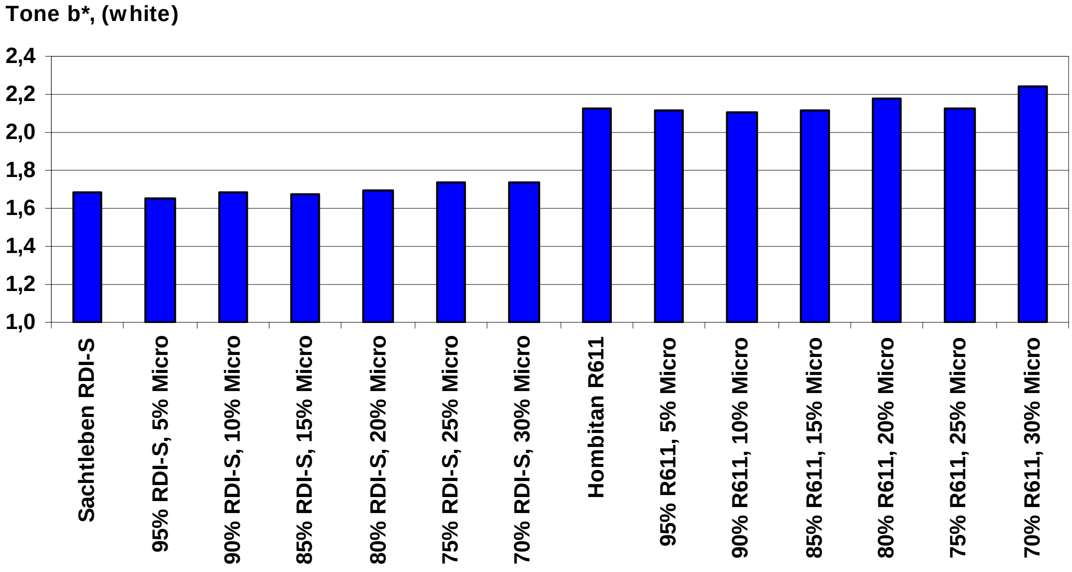

Figure 18. Tone b* of white solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

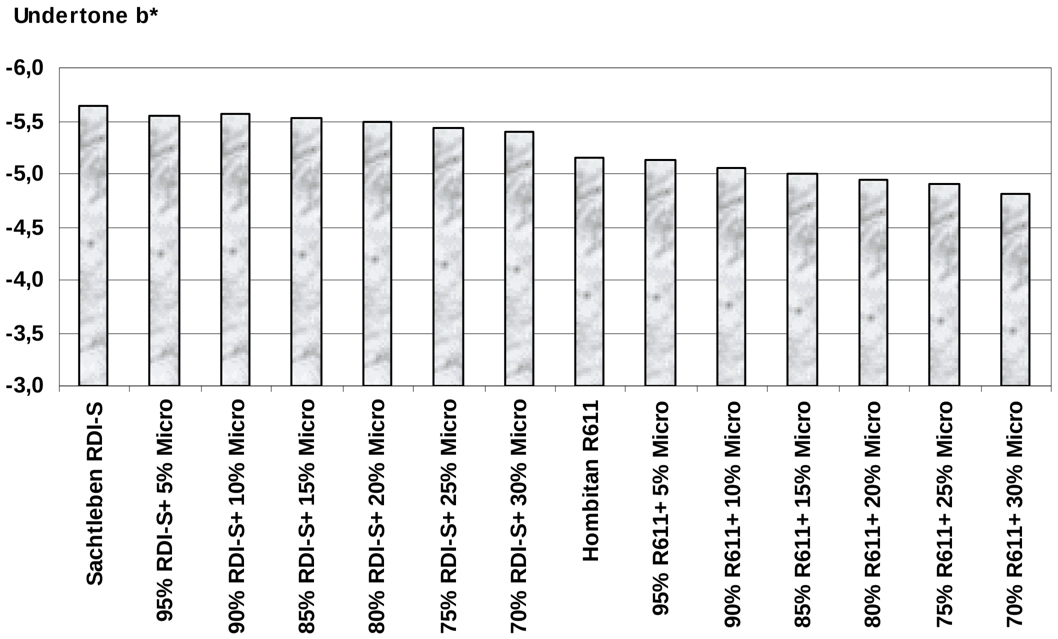

Figure 19. Undertone b* of grey water-borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

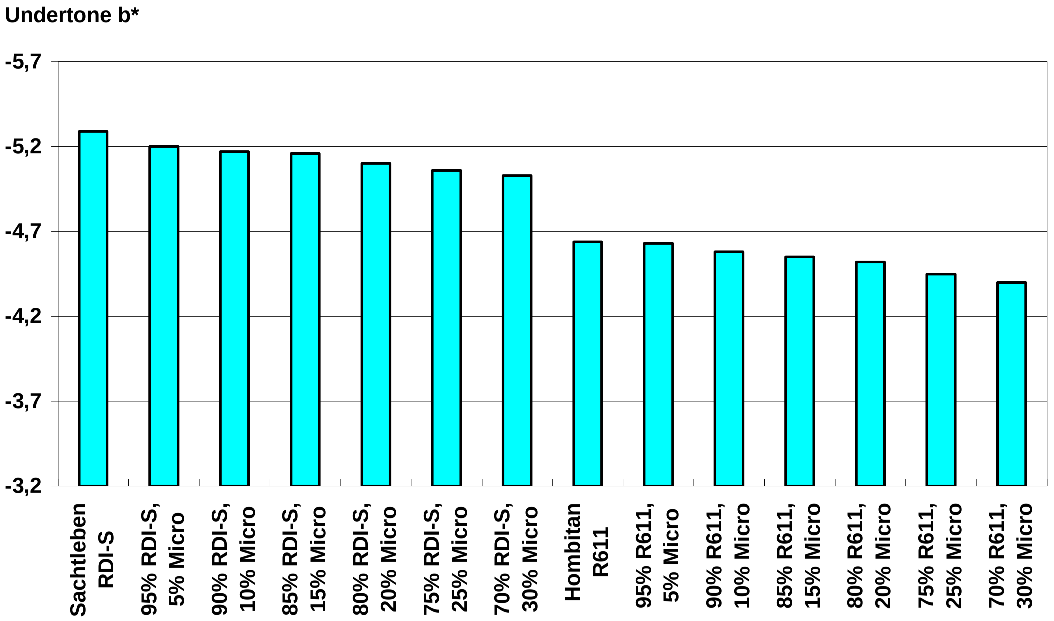

Figure 20. Undertone b* of grey solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

Contrast ratio Cr decreases when filler content increases. In water-borne paint, exception is and in solvent borne paint, exception is. Variations, 90% RDI-S+ 10% Micro (Fig. 21) and 95% RDI-S+ 5% Micro (Fig. 22) are normal and minor filler content has even a positive effect on contrast ratio.

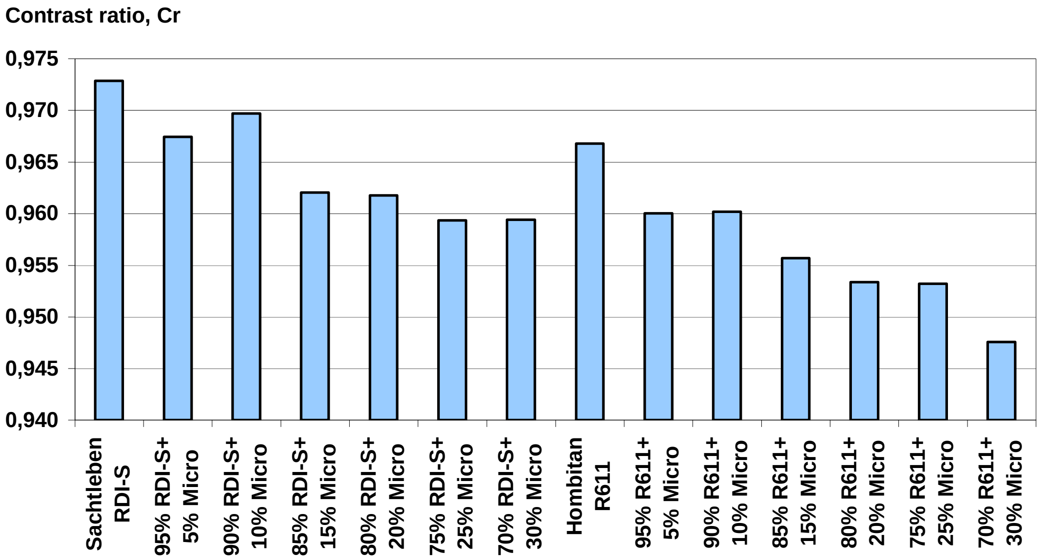

Figure 21. Contrast ratio Cr of white water-borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

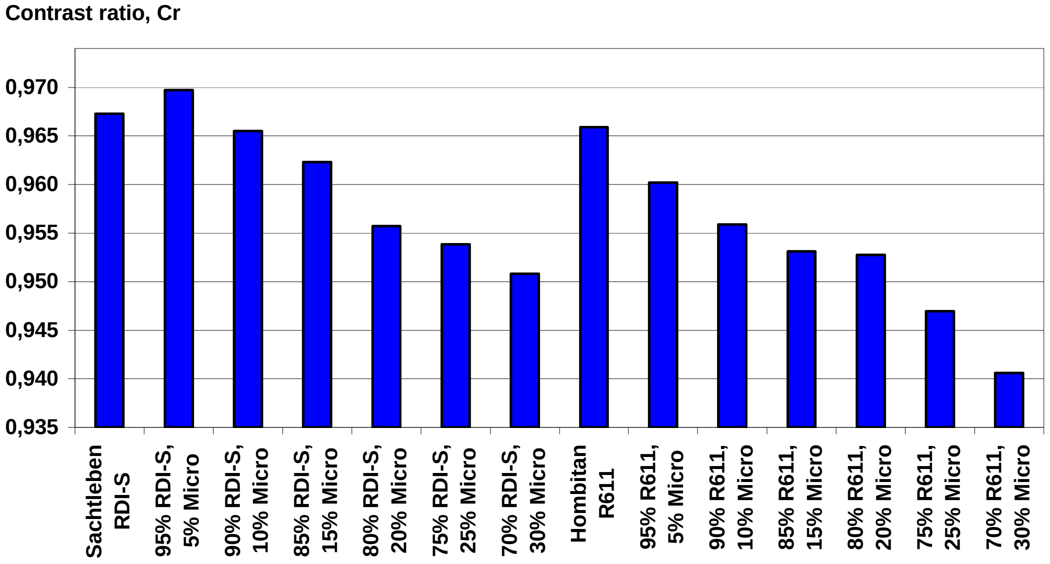

Figure 22. Contrast ratio Cr of white solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

Scattering coefficient S decreases when filler content increases (Fig. 23, Appendix 4:Fig. 3).

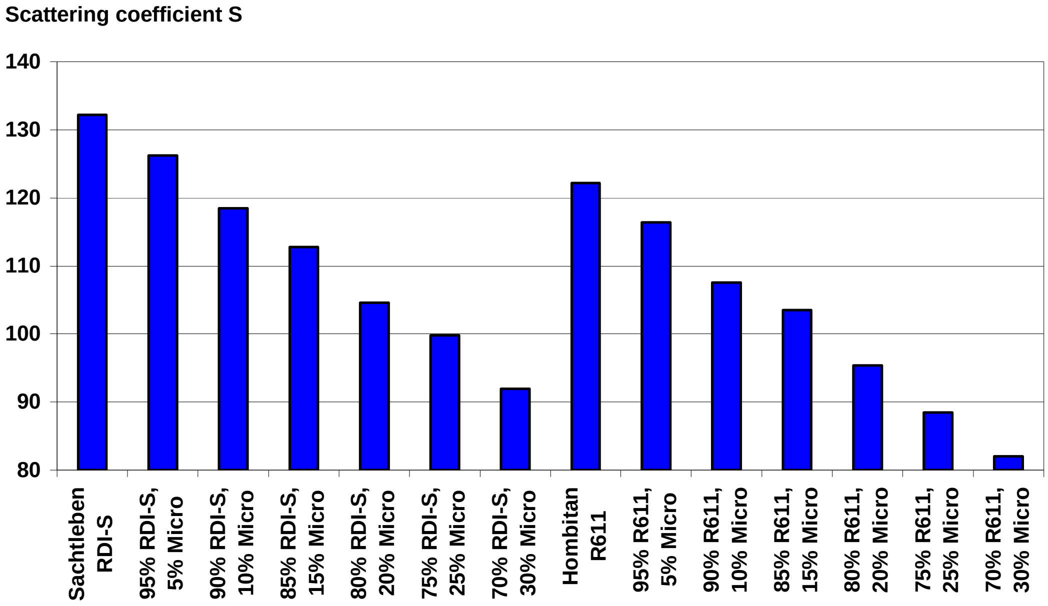

Figure 23. Scattering coefficient S of white solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

11.2 Effect of Titanium Dioxide Grade on Paint Properties

In grinding process when paints were prepared, all paints of Sachtleben RDI-S, 660 and RD3 got wet better than those with Hombitan R210 and all paints of Hombitan R210 got wet better than those with Hombitan R611 (Appendix 7: Table 1).

In the course of time viscosities grow (Fig. 24, Appendix 5: Fig. 1, Appendix 7: Fig. 1). When filler content of the paint increases, viscosity of the paint decreases. Variations in viscosity of white solvent paint are quite insignificant (Fig. 24).

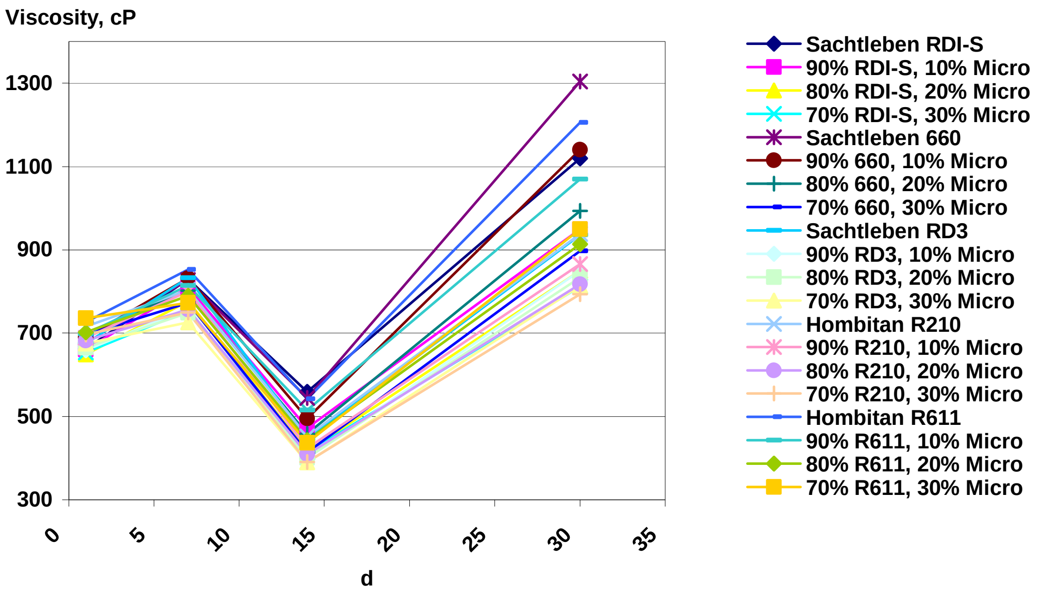

Figure 24. Viscosity of white solvent borne paint when five different pigments with Sachtleben Micro are used.

Gloss of white solvent borne paint films increase when filler content increases, except for 20º gloss of same samples (80% 660+ 20% Micro, 80% RD3+ 20% Micro, 80% R210+ 20% Micro and 90% R611+ 10% Micro) (Fig. 25). These variations are a consequence of measuring error because nothing is appeared in 60º gloss.

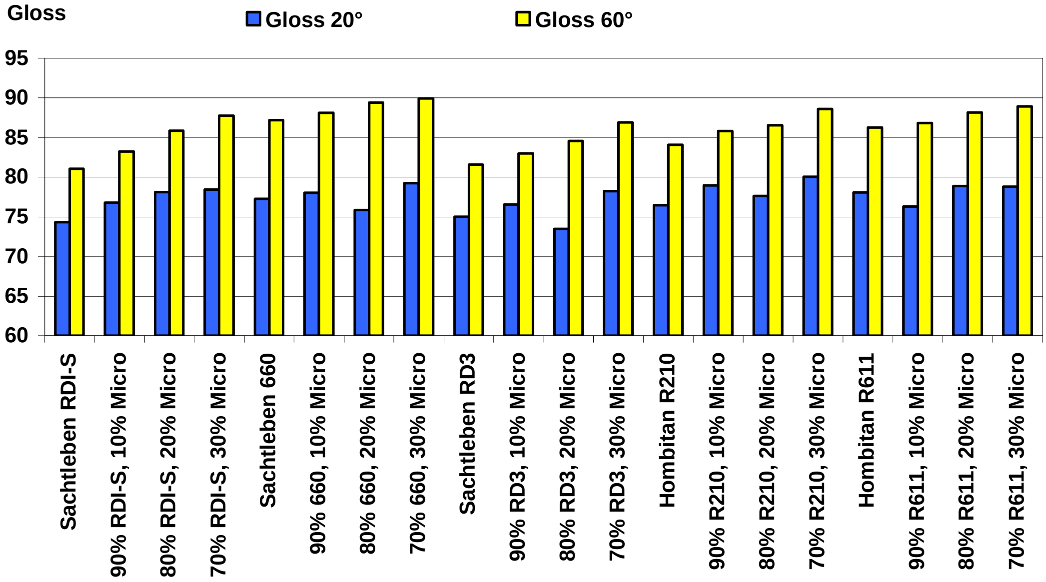

Figure 25. 20º and 60º gloss of white solvent borne paint when five different pigments with Sachtleben Micro are used.

20º and 60º gloss of water-borne paint decreases when filler content increases (Fig. 26).

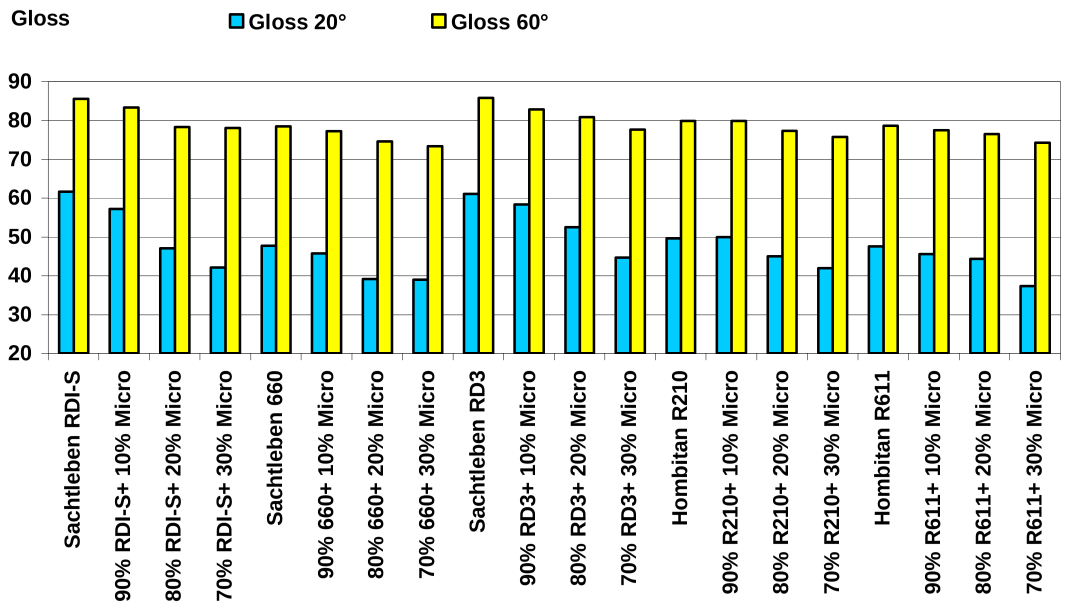

Figure 26. 20º and 60º gloss of white water-borne paint when five different pigments with Sachtleben Micro are used.

Whiteness decrease when filler content increases (Fig. 27, Appendix 5: Fig. 4 and 5, Appendix 7: Fig. 3). Remarkable variation in values of whiteness is between paint of Hombitan R210 and 70% R210+ 30% Micro (Fig. 27).

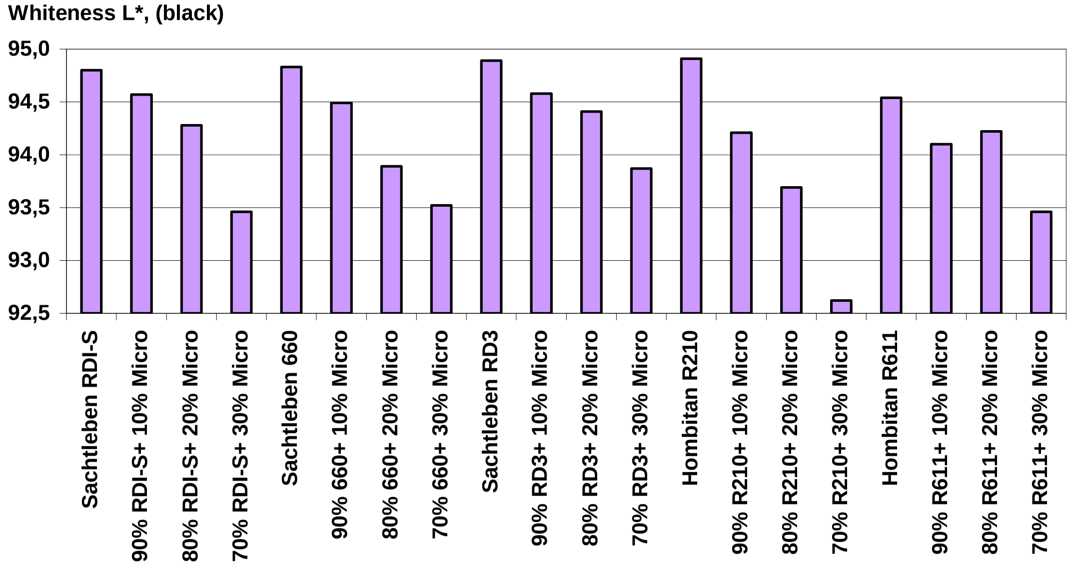

Figure 27. Whiteness L* of white water-borne paint when five different pigments with Sachtleben Micro are used.

In most paints tone b* increases when filler content increases (Fig. 28, Appendix 5: Fig. 3). Exception is paints of Sachtleben RD3 pigment (Fig. 28) and the same variation is evident in values of yellow index (Appendix 7: Fig.2).

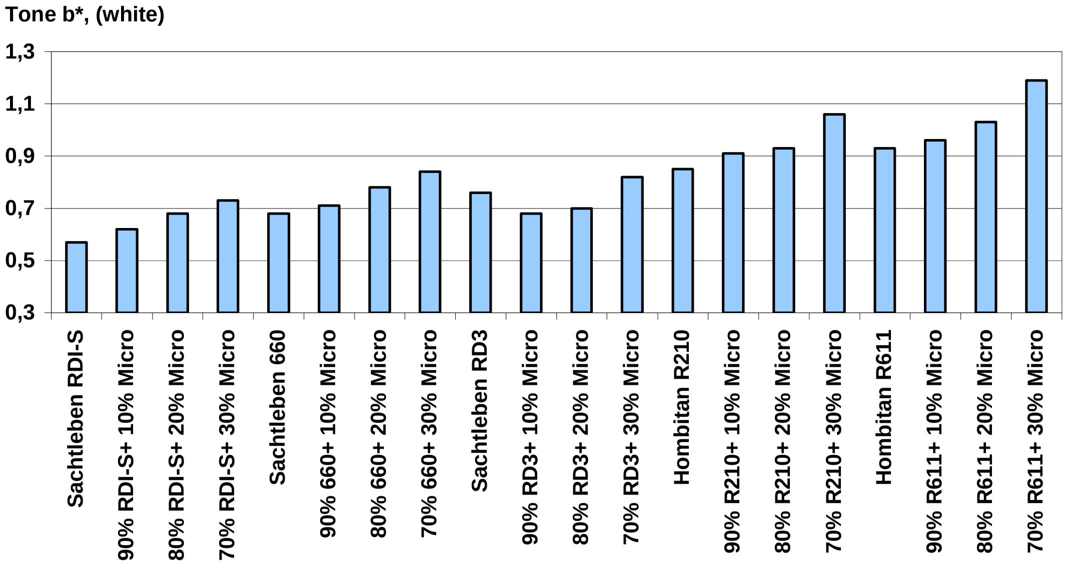

Figure 28. Tone b* of white water-borne paint when five different pigments with Sachtleben Micro is used.

In white solvent paints, values of tone b* are quite uniform and variations aren’t significant (Fig. 29).

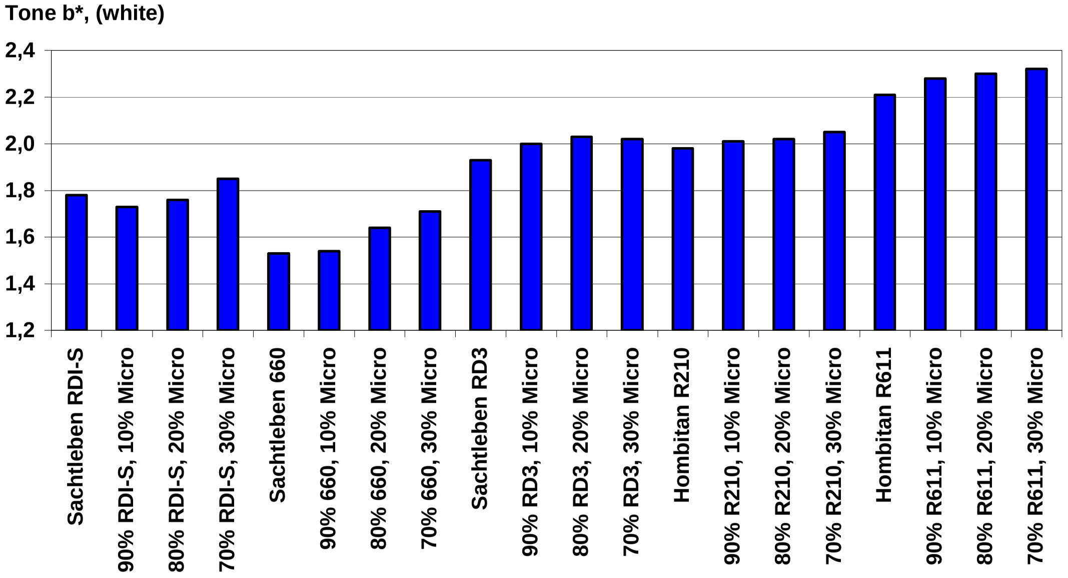

Figure 29. Tone b* of white solvent borne paint when five different pigments with Sachtleben Micro is used.

Contrast ratio Cr decreases when filler content increases. Deviations, 80% R611+ 20% Micro (Fig. 30), 90% RD3+ 10% Micro (Fig. 31) and 90% R210+ 10% Micro (Fig. 31) are meaningless.

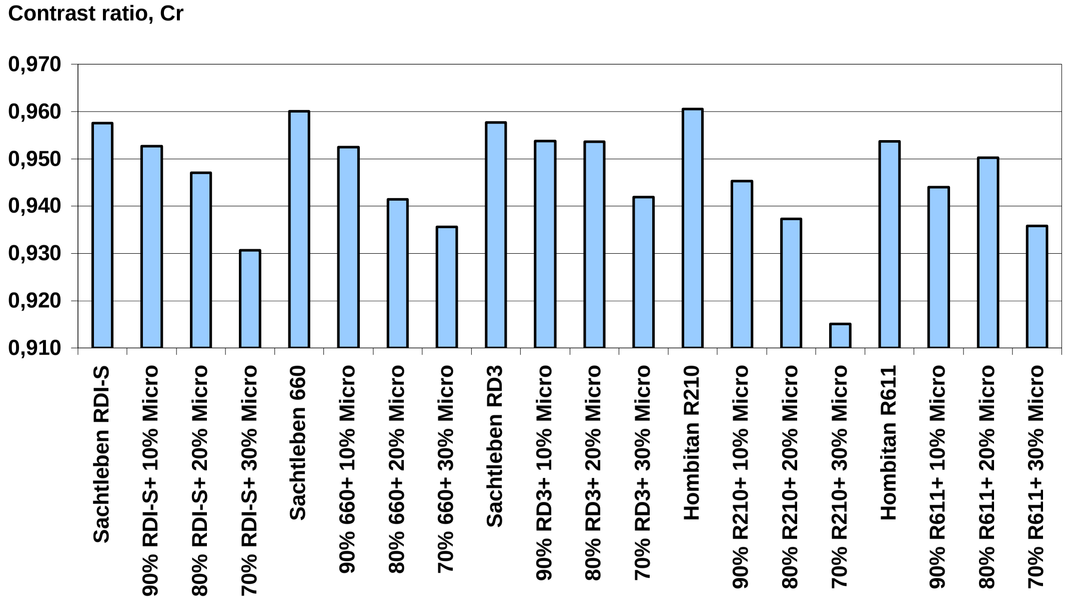

Figure 30. Contrast ratio Cr of white water-borne paint when five different pigments with Sachtleben Micro is used.

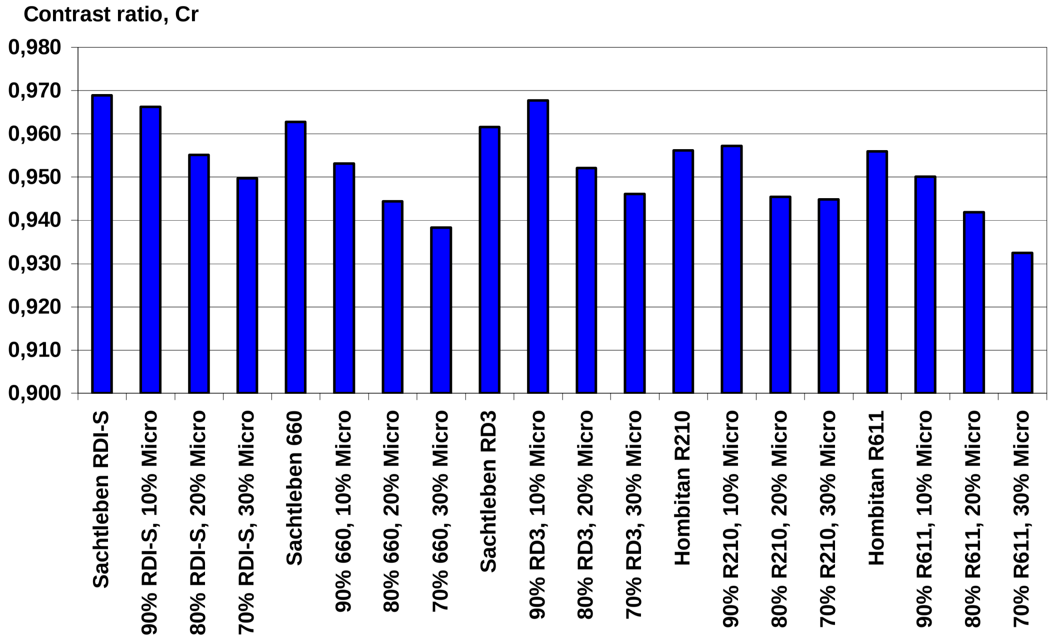

Figure 31. Contrast ratio Cr of white solvent borne paint when five different pigments with Sachtleben Micro is used.

When filler content increases, scattering coefficient decreases (Fig. 32, Appendix 5: Fig. 6).

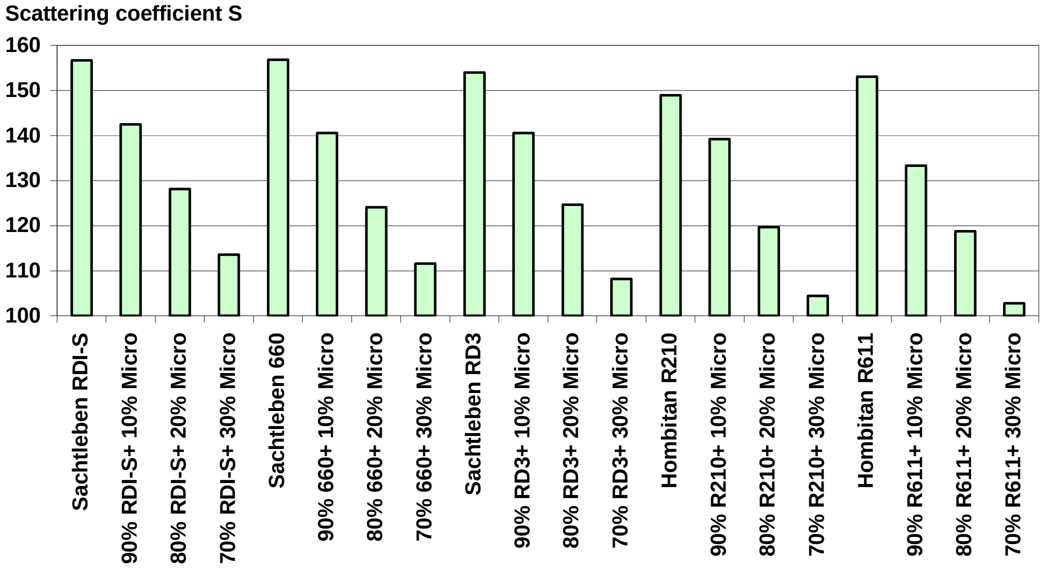

Figure 32. Scattering coefficient S of white water-borne paint when five different pigments with Sachtleben Micro is used.

Undertone turns more yellow when filler content increases (Fig. 33, Appendix 6: Fig. 1, Appendix 7: Fig. 5). Paints that contain Sachtleben RDI-S, 660 and RD3 are more blue-toned than those of Hombitan R210 and R611. Difference of 0,5 unit in undertone is significant. Undertones of paints of Sachtleben 660 change most (Fig. 33).

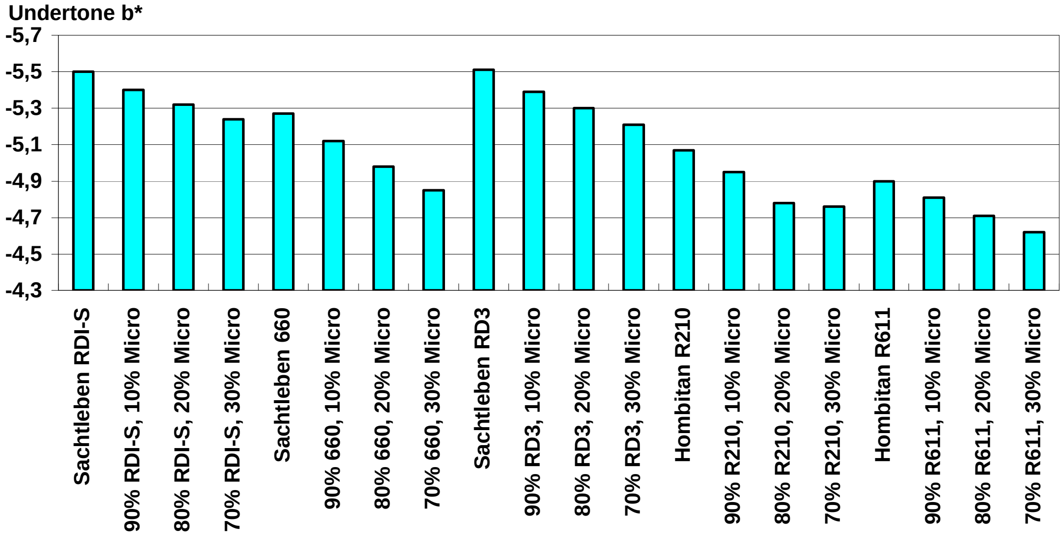

Figure 33. Undertone b* of grey solvent borne paint when five different pigments with Sachtleben Micro is used.

In grey paints, values of whiteness decreases when filler content increases (Fig. 34 and 35, Appendix 6: Fig. 2, Appendix 7: Fig. 4).

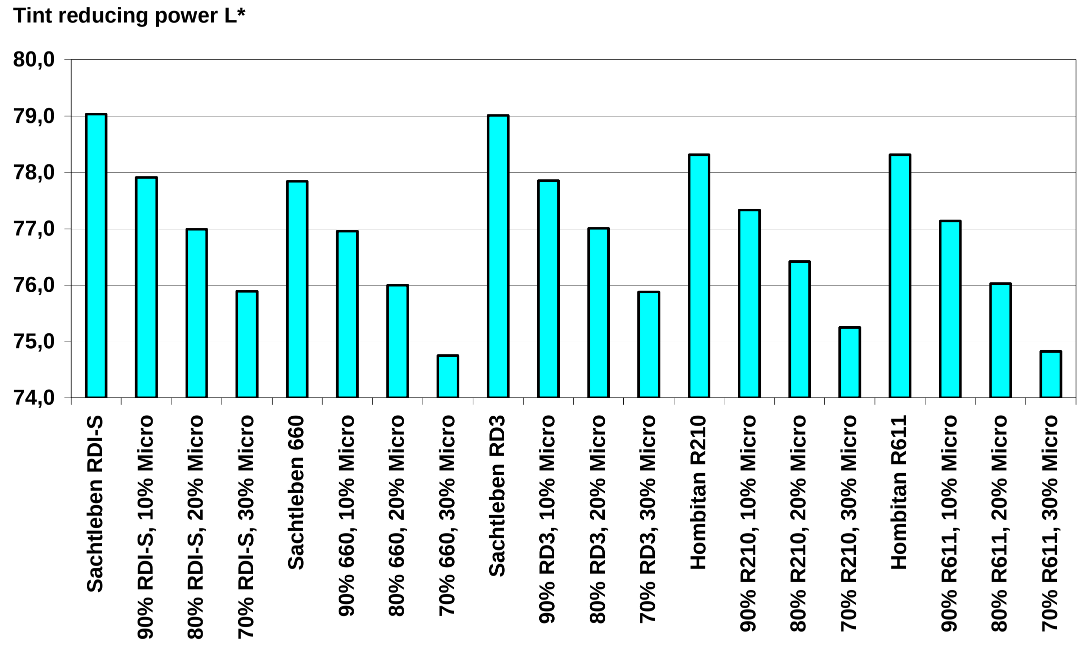

Figure 34. Tint reducing power L* of grey solvent borne paint when five different pigments with Sachtleben Micro is used.

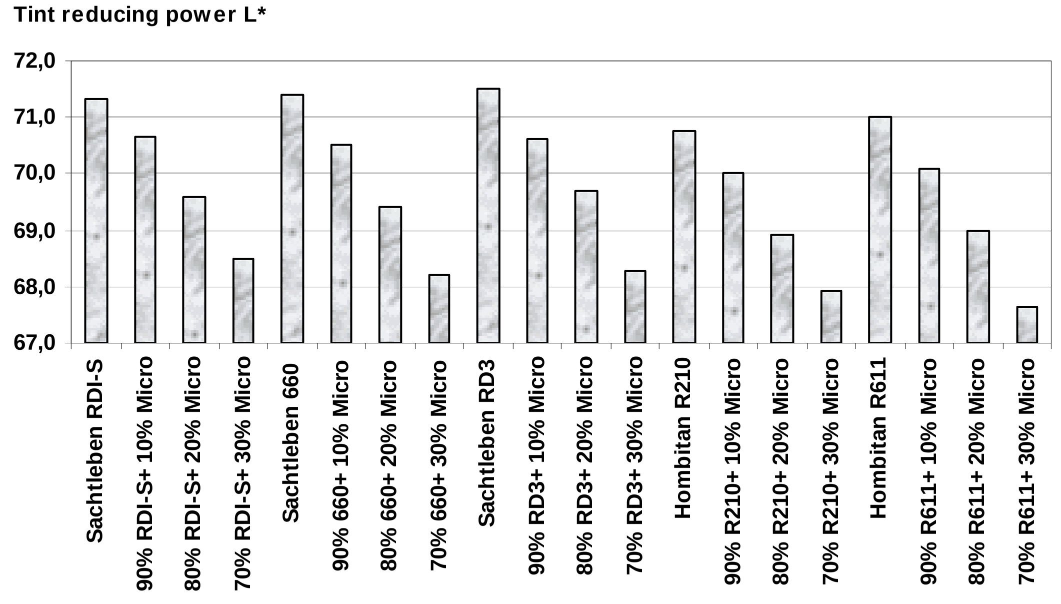

Figure 35. Tint reducing power L* of grey water-borne paint when five different pigments with Sachtleben Micro is used.

11.3 Comparison of Performance of Mechanical Mixtures of Filler and TiO_2 to Performance of Sachtleben K40 in Paints

In grinding process when paints were prepared, pigment with Sachtleben Micro filler got wet better than those with Amazon Premium filler (Appendix 10: Table 1). In preparation of 60% RDI-S+ 40% Amazon, 1/3 of water was added in stage of grinding and in preparation of 60% R210+ 40% Amazon, 2/3 of water was added in stage of grinding. While in preparation of K40, all water was added in grinding. K40 didn’t disperse properly to water-borne paint system and it formed quite dense paint.

When Sachtleben Micro filler is used, viscosities are lower than when Amazon Premium filler is used (Fig. 36 and 37, Appendix 8: Fig. 1). Viscosities were measured 1, 7 and 14 days after date of the paint preparation. Viscosities of K40 and paints of Amazon as filler are nearly same in solvent borne paints (Fig. 36).

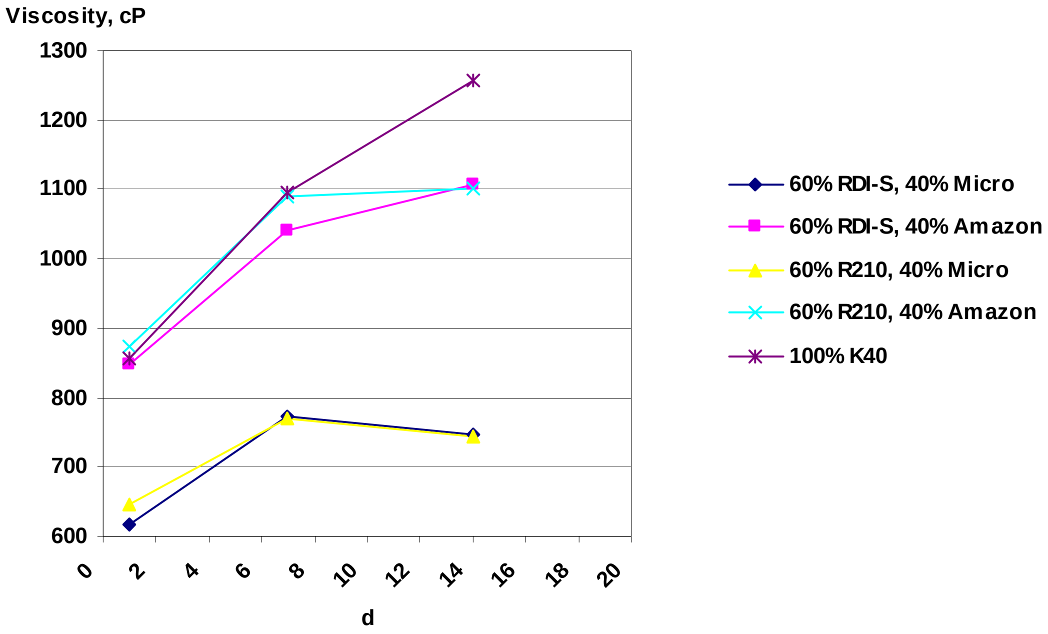

Figure 36. Viscosity of white solvent borne paint with K40, RDI-S or R210 and 40 % of Micro or Amazon.

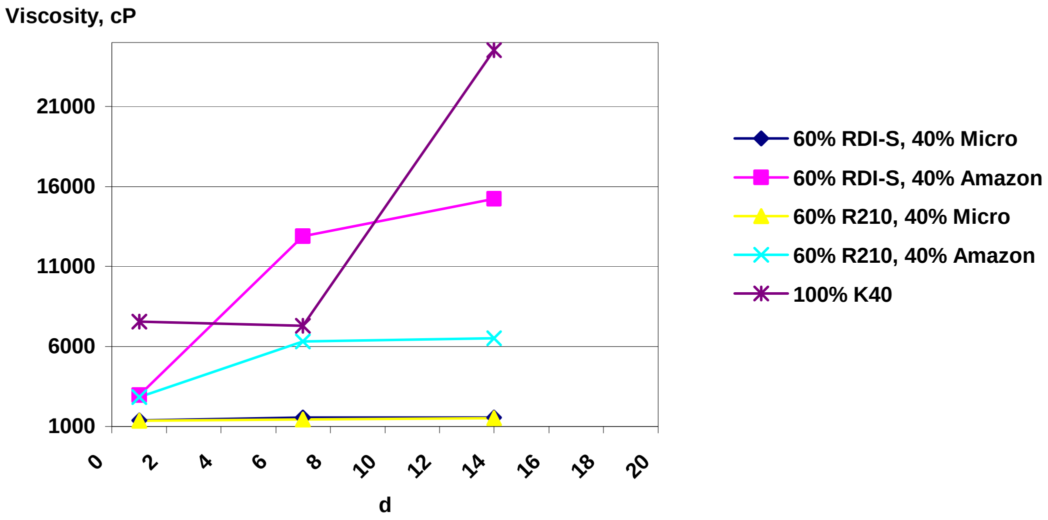

Figure 37. Viscosity of white water-borne paint with K40, RDI-S or R210 and 40 % of Micro or Amazon.

Paints that contain either Sachtleben Micro or Amazon Premium as filler didn't have big differences in glosses. 20º and 60º gloss of mechanical mixtures are better than those of K40 in water-borne paint (Fig. 38).

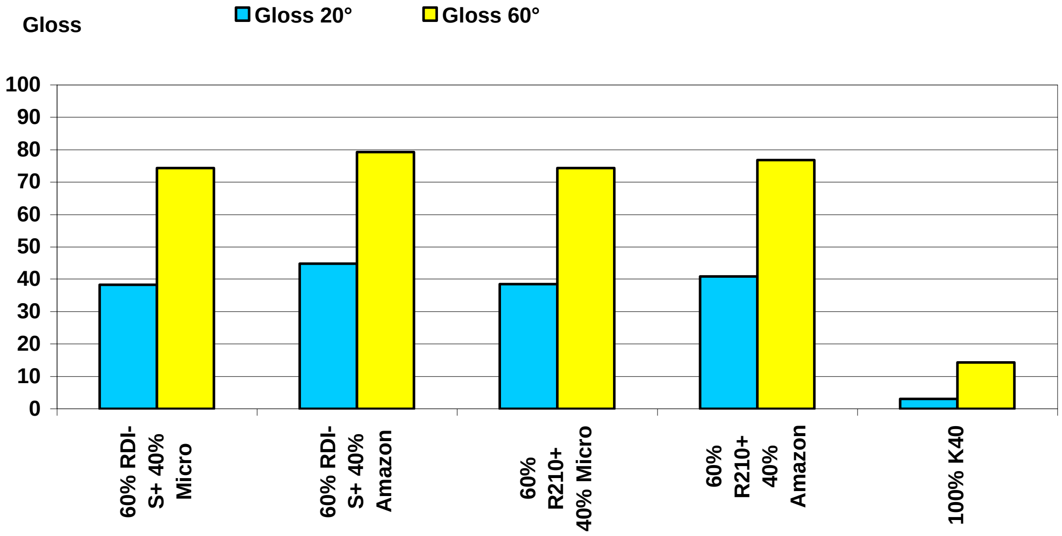

Figure 38. 20º and 60º gloss of white water-borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

In solvent borne paints, paints that contain Sachtleben Micro as filler have better glosses than those of Amazon Premium. 20º and 60º gloss of K40 are better than glosses of paints that contain Amazon Premium as filler (Fig. 39).

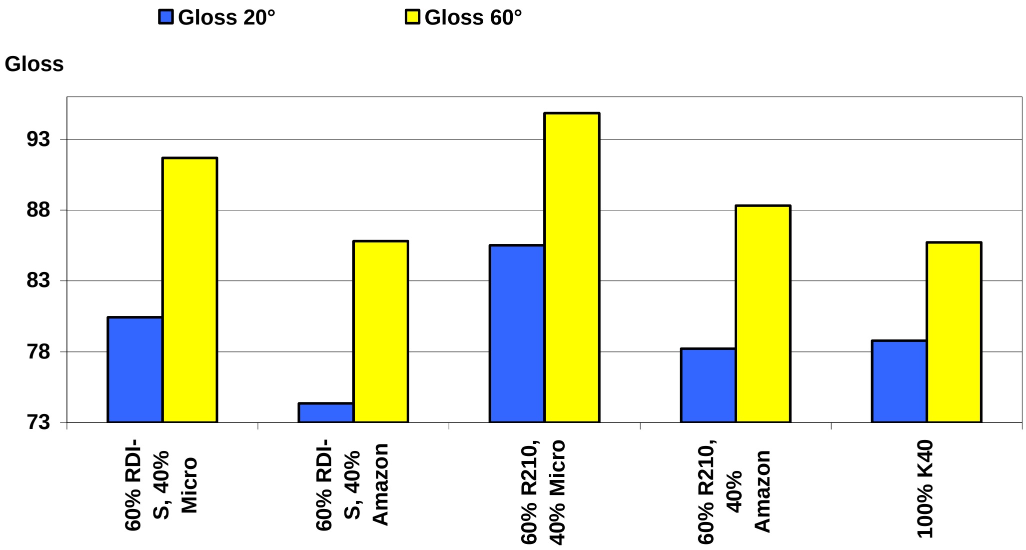

Figure 39. 20º and 60º gloss of white solvent borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

Tone b* of K40 paint is higher than tones of other paints (Fig. 40, Appendix 8: Fig. 2 and 5, Appendix 10: Fig. 1). Tone b* is lower when Sachtleben Micro is used as filler than when Amazon Premium is used. 60% RDI-S+ 40% Amazon is more blue-toned than K40.

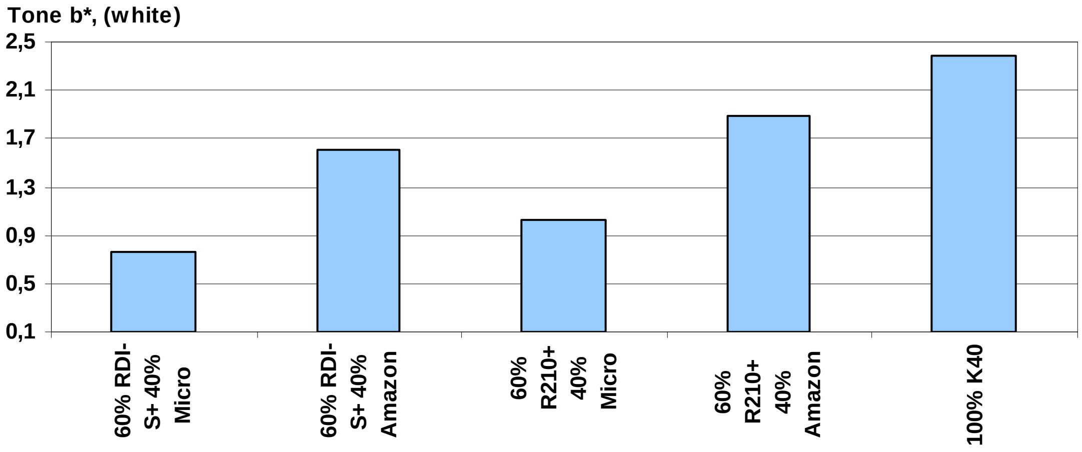

Figure 40. Tone b* of white water-borne paint with K40, RDI-S or R210 and 40 % of Micro or Amazon.

Paints that contain either Sachtleben Micro or Amazon Premium as filler didn't have big differences in whiteness. Difference of 0,5 unit in whiteness is significant. Whitenesses of mechanical mixtures are better than that of K40 (Fig. 41, Appendix 8: Fig. 3 and 4, Appendix 10: Fig. 2).

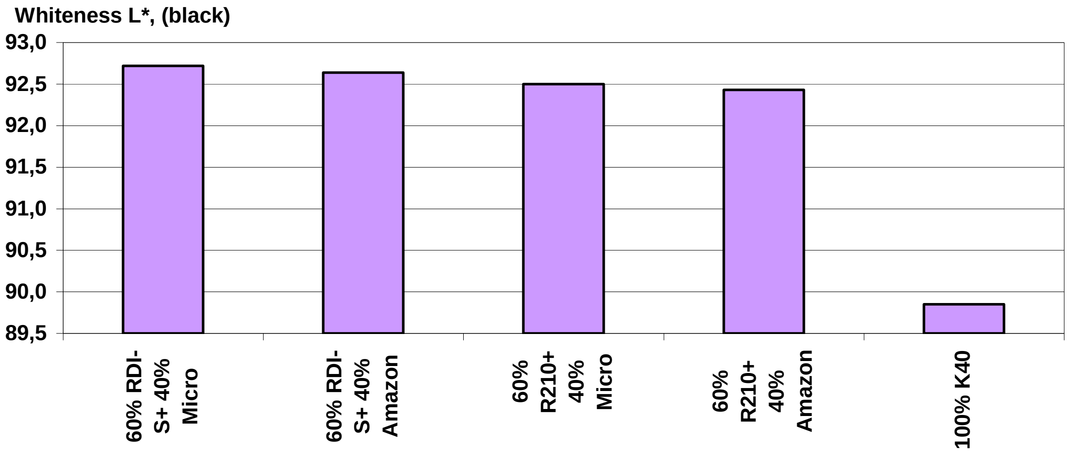

Figure 41. Whiteness L* of white water-borne paint with K40, RDI-S or R210 and 40 % of Micro or Amazon.

Water-borne paint K40 and paints that contain Sachtleben Micro filler have lower S values than paints that contain Amazon Premium filler (Fig. 42 and 43).

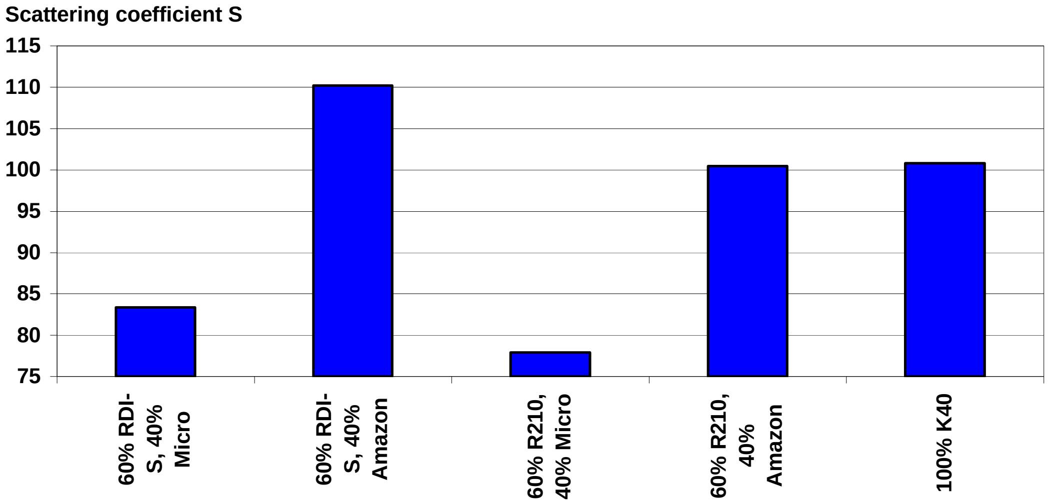

Figure 42. Scattering coefficient S of white solvent borne paint with K40, RDI-S or R210 and 40 % of Micro or Amazon.

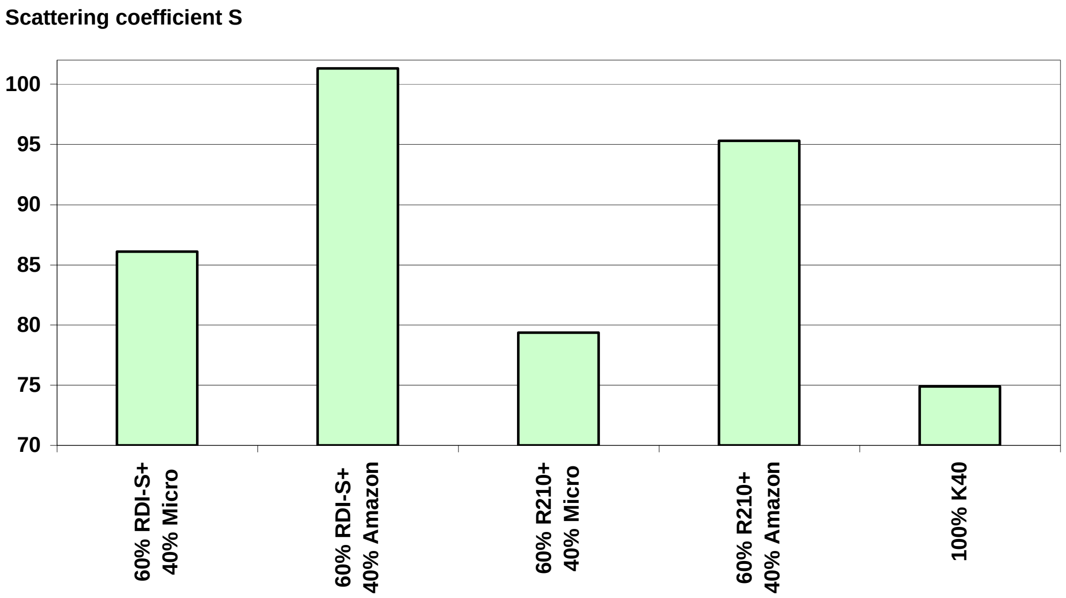

Figure 43. Scattering coefficient S of white water-borne paint with K40, RDI-S or R210 and 40 % of Micro or Amazon.

Paints that contain Sachtleben Micro have nearly same contrast ratios like also paints that contain Amazon Premium, contrast ratio of K40 is little bit lower (Fig. 44). Contrast ratio Cr of white solvent borne paint is represented in appendix 8 (Fig. 6).

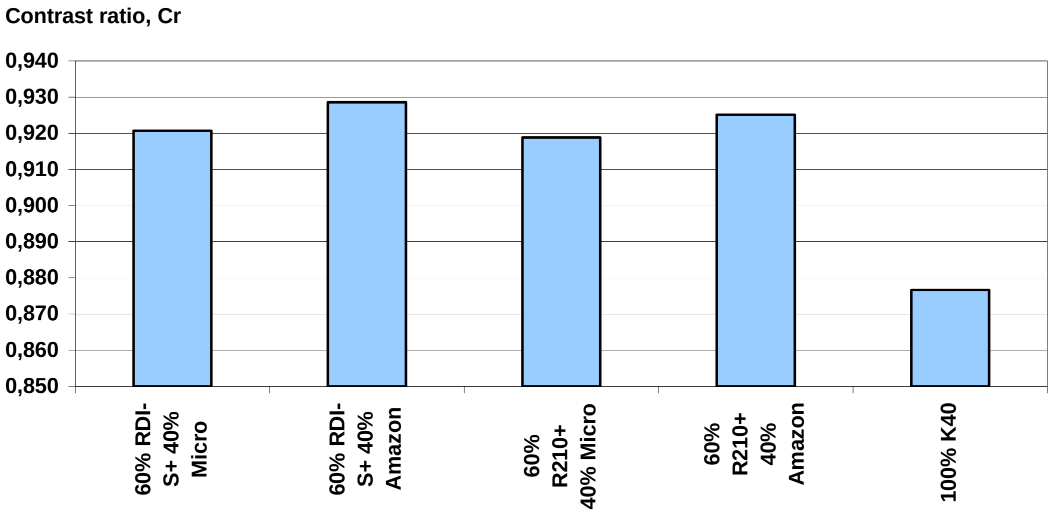

Figure 44. Contrast ratio Cr of white water-borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

In grey water-borne paints, whiteness of paint film with K40 is substantially lower than that of other samples (Fig. 45 and Appendix 10: Fig. 3). Whitenesses of grey solvent borne paint are represented in appendix 9 (Fig. 3 and 4).

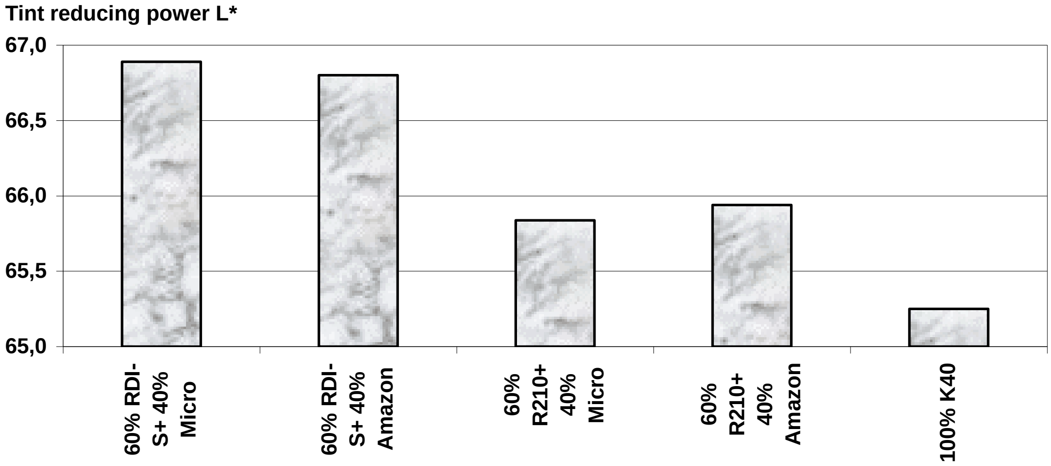

Figure 45. Tint reducing power Y of grey water-borne paint with K40, RDI-S or R210 and 40 % of Micro or Amazon.

Undertones of paint films with RDI-S are higher than that of other paints and undertone b* of paint film with K40 is lowest of these paints (Fig. 46, Appendix 9: Fig. 1 and 2).

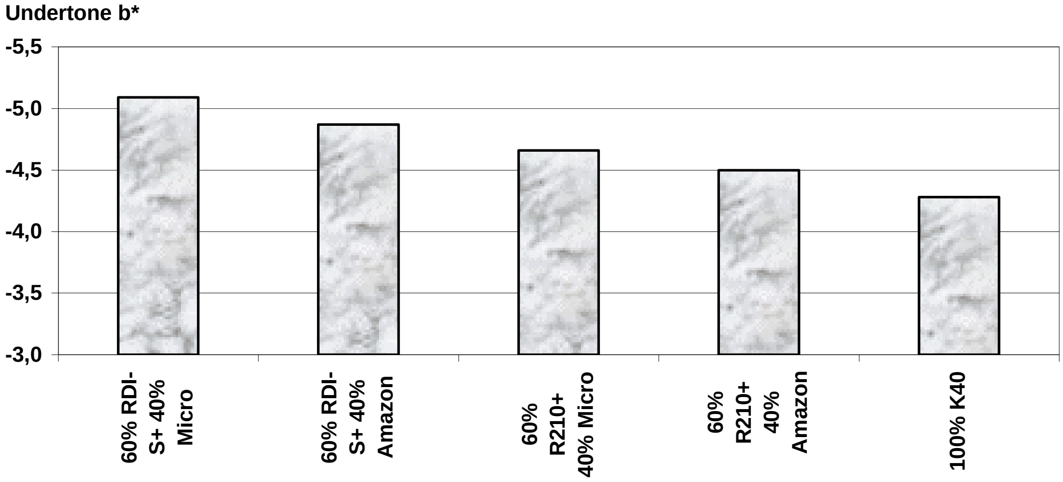

Figure 46. Undertone b* of grey water-borne paint with K40, RDI-S or R210 and 40 % of Micro or Amazon.

12 CONSIDERATION OF RESULTS

In the course of time, paint starts to flocculate and flocculation induces the increase of viscosity. Paints that has Sachtleben Micro as filler, has lower viscosities than paints that where Amazon Premium is as filler. This is because Sachtleben Micro disperses much better to paint than Amazon Premium does.

Particle size of fillers (Sachtleben Micro and Amazon Premium) are notably smaller than that of TiO_2 pigments. Thus, the better paint is dispersed, the better is the gloss. Variations of gloss arise from the quality of appliqued paint film. Roughness of paint film, air bubbles and contaminants interact with results of measurement. Water-borne paints of Hombitan R210 and R611 disperse worser than other paints. Glosses of those paints decrease when filler content increases and that is because the more paint involves filler, the worser dispersing works out.

Fillers have much lower refractive index than TiO_2. Thus, fillers decrease whiteness of the paint. On the grounds of results, fillers may produce a yellowness of paint. Fillers contain contaminants, like coloured oxides (Al_2O_3, SiO_2, BaO, SO_3). In grey paints, blue undertone of paint is caused by small particle size. However, the more paint contains filler, the more blue is tone of paint. When paint contains more filler, dispersion was more unsuccessful. And this is why, particle sizes were not become so small and furthermore paint is less blue toned than it should be.

When filler content increases, scattering coefficient S decreases. The higher is S, the more opaque is the paint film. So, the more paint contains filler, the worser is its opacity. TiO_2 gives opacity but filler doesn’t.

13 SUMMARY OF RESULTS AND CONCLUSIONS

Increase of filler concentration has evidently effect on characters of paint. Suitable filler content depends on desirable characters of the paint. If gloss of the paint film is desired character, fillers are worthwhile to use. 10% filler content is quite suitable taking into consideration gloss, whiteness and opacity. When the filler percentage is 30, it interacts quite a bit with characters of paint, like opacity, tone and whiteness. Costs of the paint can be reduced while replacing titanium dioxide with filler.

Comparing pigments to each other, results of Sachtleben RDI-S, Sachtleben 660 and Sachtleben RD3 were most uniform when taking into account all measured characters. Variation of values of whiteness and tone between paint that contains no filler and paint which filler content is 30%, was smaller in paints of Sachtleben RDI-S, 660 and RD3 than in paints of Hombitan R611 and R210. Yellow index, tone and whiteness are worse in paints of Hombitan R210 and Hombitan R611 when compared to other pigments. 20º and 60º gloss were best in solvent borne paints when Sachtleben Micro was used with Sachtleben 660.

Scattering coefficients were best in paints that contain Amazon Premium as filler whereupon these paints are most opaque. Gloss and whiteness of paints that contain Sachtleben Micro as filler were better than other prepared paints. Viscosities of paints with Sachtleben Micro were lower when compared to those of Amazon Premium. Sachtleben Micro seems to perform better as filler than Amazon Premium. Sachtleben K40 functions better in solvent borne than in water-borne paints. Whiteness of mechanical mixtures of titanium dioxide and filler was good. In these paint systems, mechanical mixtures of titanium dioxide and filler seems to perform better than K40.

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Characters of pigments and fillers

Table 1. Studied pigments.

	Sachtleben RDI-S 804344049	Sachtleben RD3 721322013	Sachtleben 660 733212002	Hombitan R611 K4614	Hombitan R210 K4615
Brightness L*	97,78	97,96	97,84	97,95	98,13
Tone b*	2,47	2,44	2,21	2,55	2,51
Undertone b*	-7,53	-7,63	-7,22	-6,79	-6,91
Tinting strenght L*	64,74	64,70	64,26	63,74	63,81
Particle size (nm)	279	275	288	307	299
Crystal size (nm) mean/ sd/ mode	216/ 56/ 198	220/ 50/ 200	221/ 55/ 197	216/ 61/ 197	210/ 52/ 186
TiO_2 %	94,7	94,0	93,9	93,4	93,6
Al_2O_3 %	3,26	3,46	2,24	3,63	4,32
SiO_2 %	0,06	0,06	2,33	1,08	0,22
ZnO %	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
P_2O_5 %	0,116	0,40	0,134	0,33	0,26
Sb_2O_3 %	< 0,005	0,081	0,005	< 0,005	0,006
Fe_2O_3 %	33,0	36,0	35,0	40,0	37,0
ZrO_2 %	0,079	0,589	0,079	0,020	0,020
Nb_2O_5 %	0,1261	0,047	0,0439	0,030	0,030
K_2O %	0,019	0,021	0,037	0,040	0,030

Table 2. Studied fillers.

	Sachtleben Micro	Amazon Premium
Brightness L*	99,10	94,95
Tone b*	0,95	4,26
Undertone b*	-1,25	-2,49
Tinting strenght L*	27,41	30,64
Particle size (nm) d(0,1) µm	0,959	0,142
d(0,5) µm	1,783	0,205
d(0,9) µm	3,148	0,652
Na_2O %	0,73	0,23
Al_2O_3 %	0,7	44,16
SiO_2 %		51,79
SO_3 %	34,9	0,16
TiO_2 %		1,21
Fe_2O_3 %		2,05
BaO %	61,8	
P_2O_5 %		0,27
K_2O %		0,01
ZrO_2 %		0,01

Effect of barium sulphate filler concentration on properties of white solvent borne paint

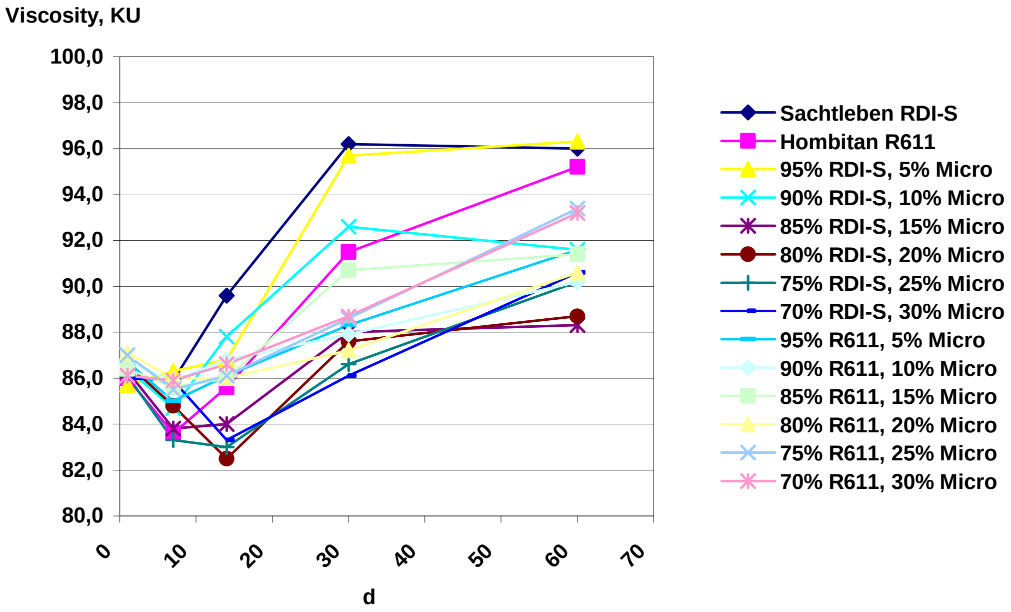

Figure 1. Viscosity of white solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30% of Sachtleben Micro.

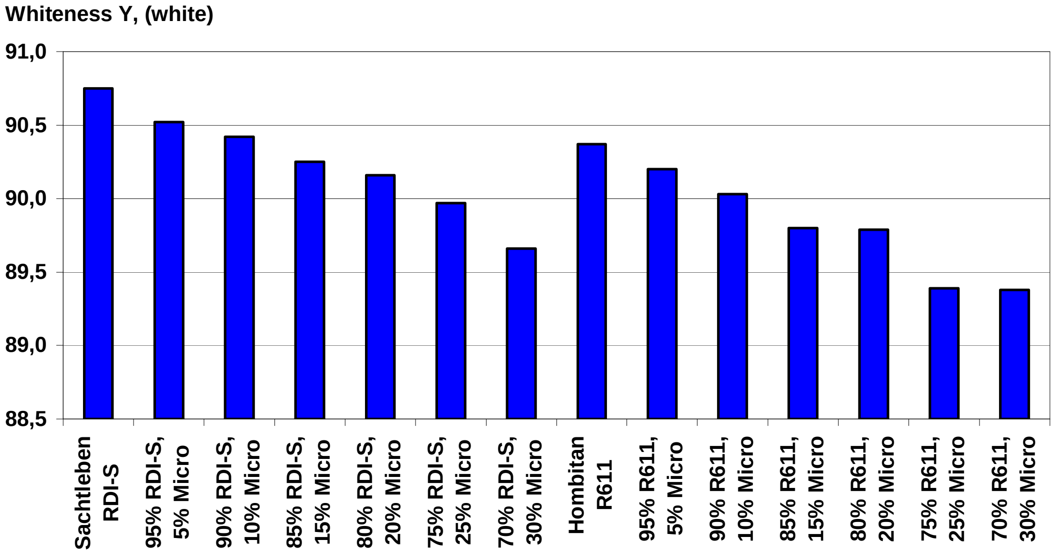

Figure 2. Whiteness Y of white solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

Effect of barium sulphate filler concentration on properties of white solvent borne paint

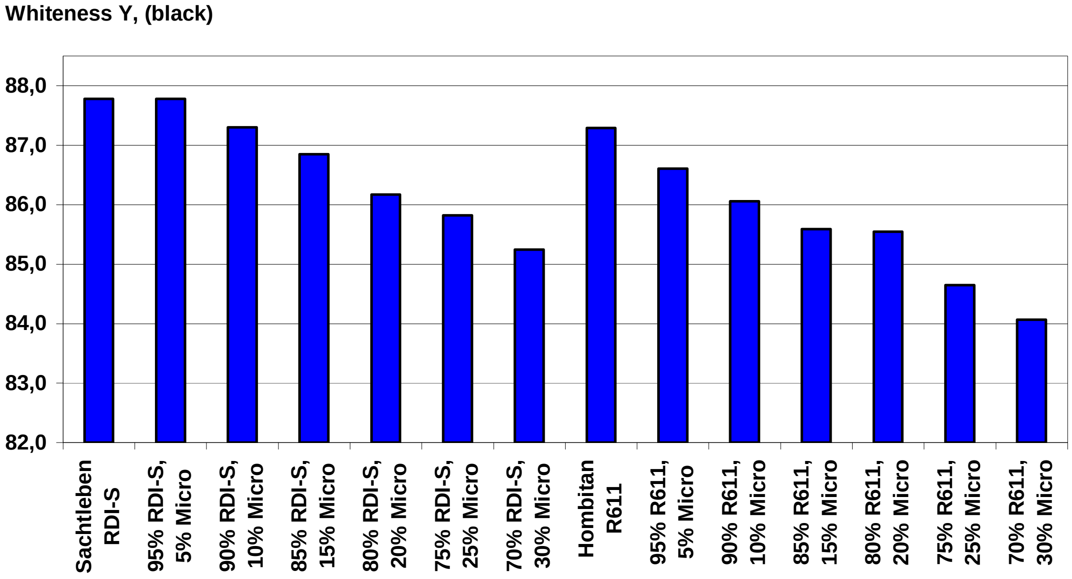

Figure 3. Whiteness Y of white solvent borne paint on black backing with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

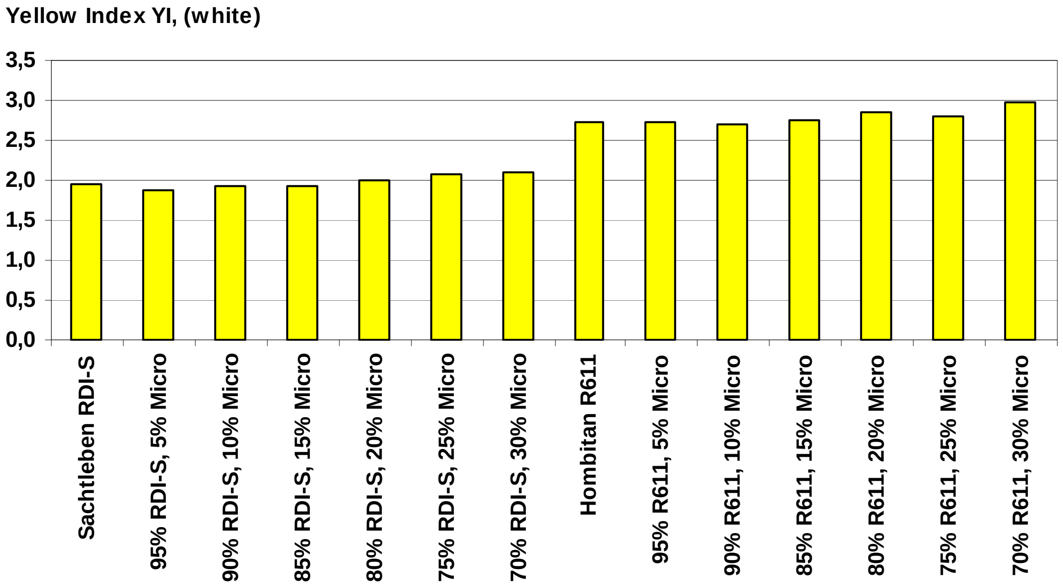

Figure 4. Yellow index YI of white solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

Effect of barium sulphate filler concentration on properties of grey solvent borne paint

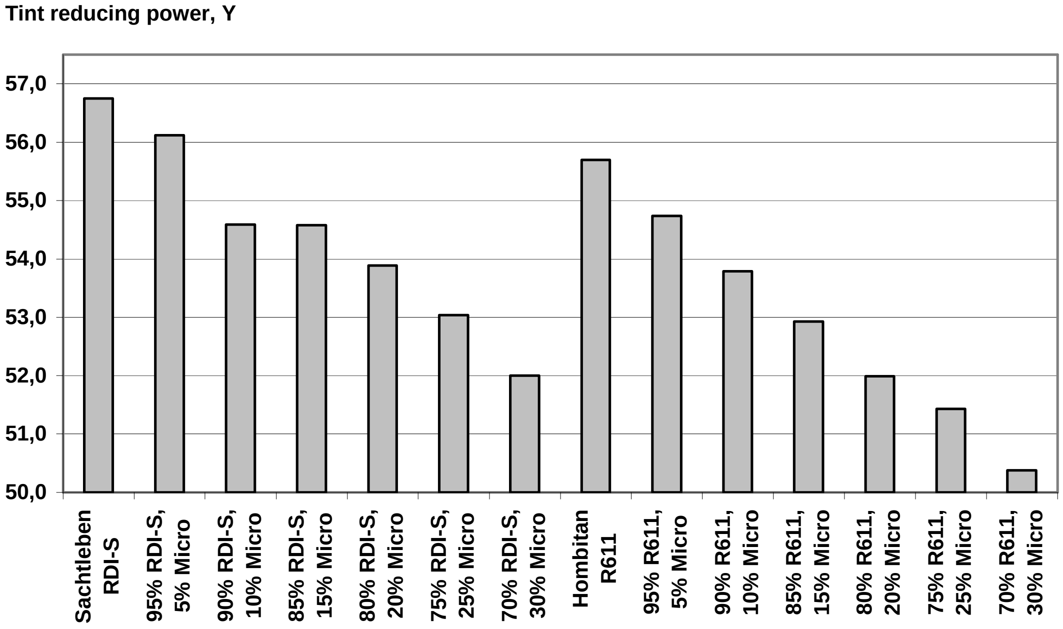

Figure 1. Tint reducing power Y of grey solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

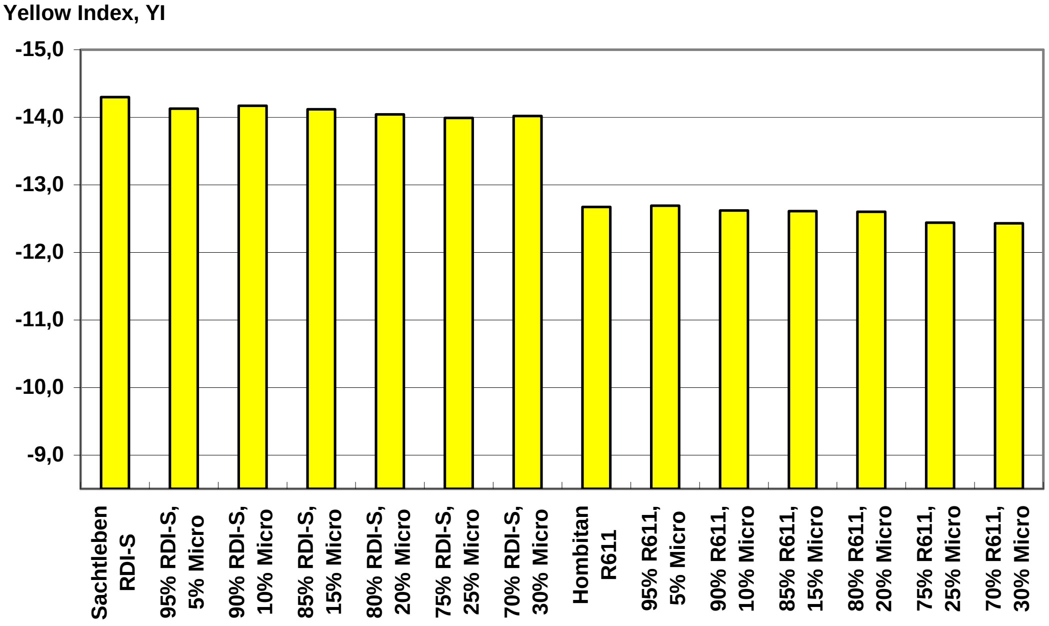

Figure 2. Yellow index YI of grey solvent borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

Effect of barium sulphate filler concentration on properties of water-borne paint

Table 1. Grinding temperatures.

		T/°C
1	Sachtleben RDI-S	34
2	Hombitan R611	35
3	95% RDI-S+ 5% Sachtleben Micro	34
4	90% RDI-S+ 10% Sachtleben Micro	34
5	85% RDI-S+ 15% Sachtleben Micro	33
6	80% RDI-S+ 20% Sachtleben Micro	34
7	75% RDI-S+ 25% Sachtleben Micro	34
8	70% RDI-S+ 30% Sachtleben Micro	34
9	95% R611+ 5% Sachtleben Micro	35
10	90% R611+ 10% Sachtleben Micro	36
11	85% R611+ 15% Sachtleben Micro	34
12	80% R611+ 20% Sachtleben Micro	38
13	75% R611+ 25% Sachtleben Micro	35
14	70% R611+ 30% Sachtleben Micro	38

Effect of barium sulphate filler concentration on properties water-borne paint

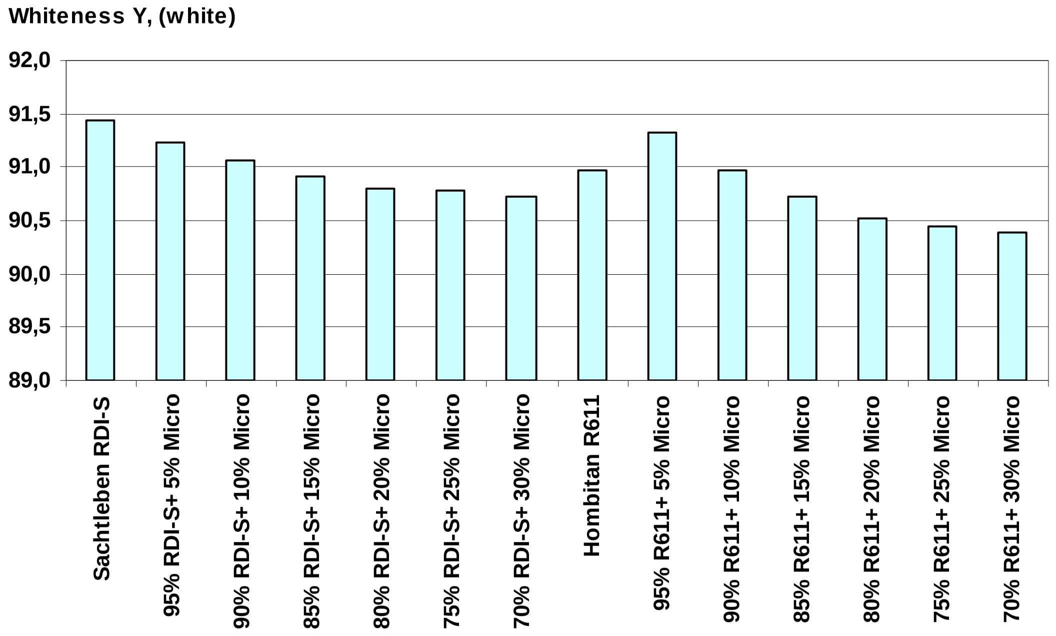

Figure 1. Whiteness Y of white water-borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

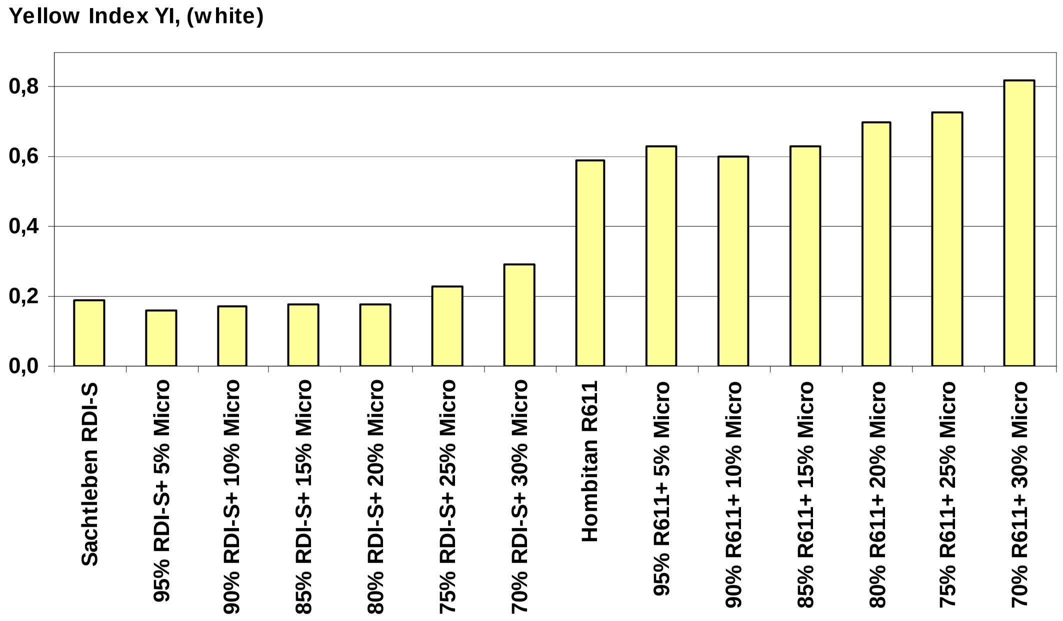

Figure 2. Yellow index YI of white water-borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

Effect of barium sulphate filler concentration on properties water-borne paint

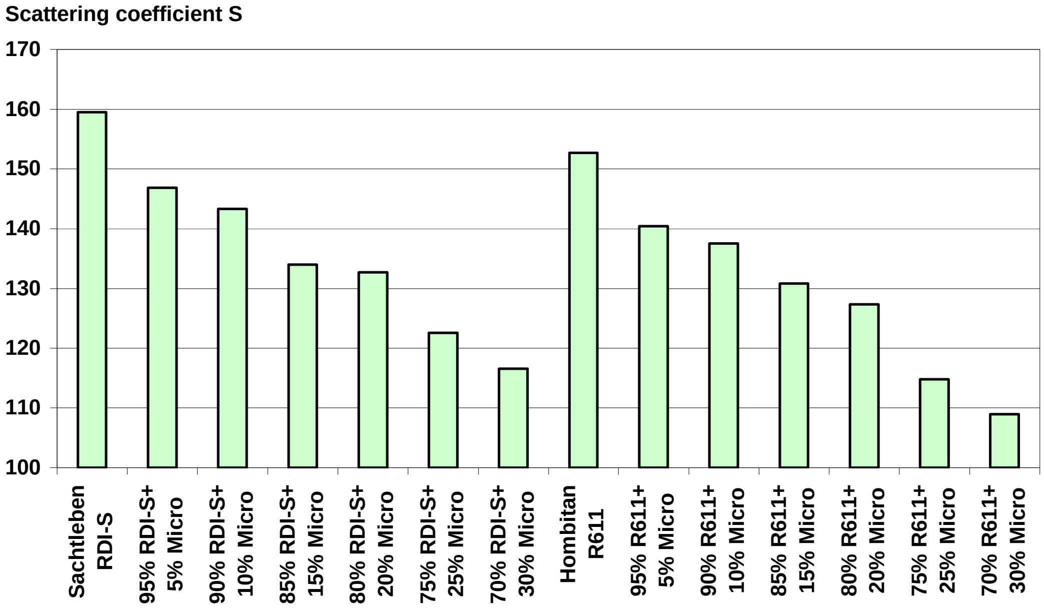

Figure 3. Scattering coefficient S of white water-borne paint with Sachtleben RDI-S or Hombitan R611 and 5-30 % of Sachtleben Micro.

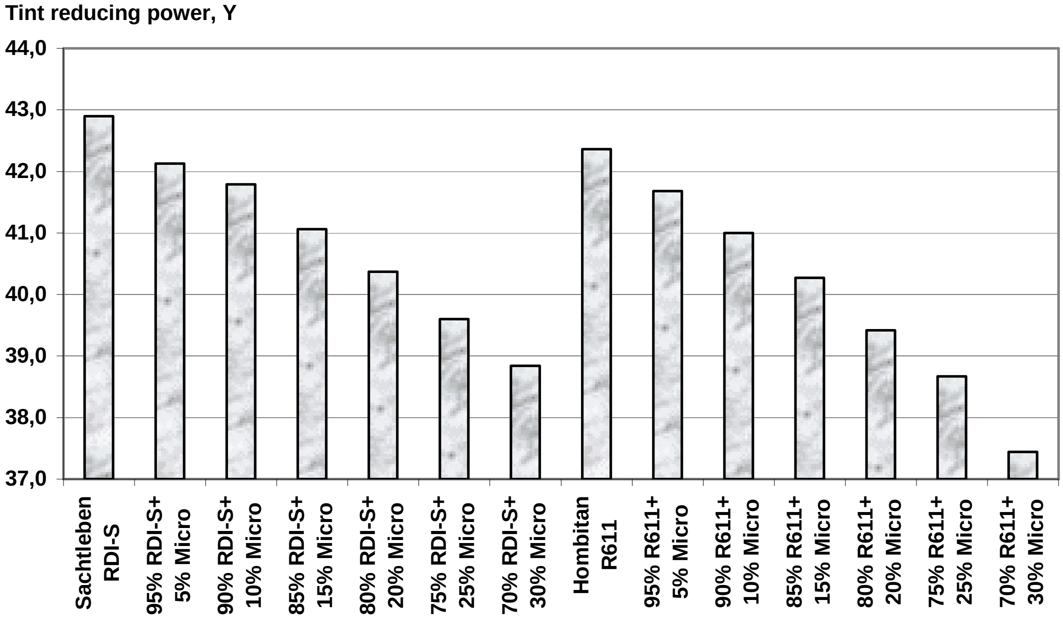

Figure 4. Tint reducing power Y of grey water-borne paint with RDI-S or R611 and 5-30 % of Micro.

Effect of titanium dioxide grade on properties of white solvent borne paint

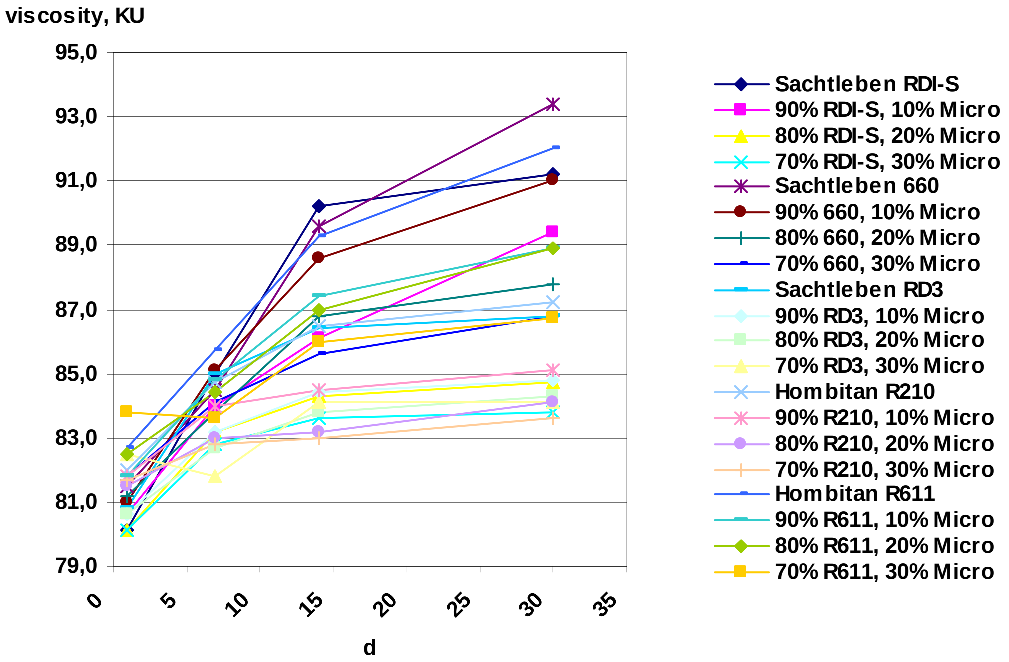

Figure 1. Viscosity of white solvent borne paint when five different pigments with Sachtleben Micro are used.

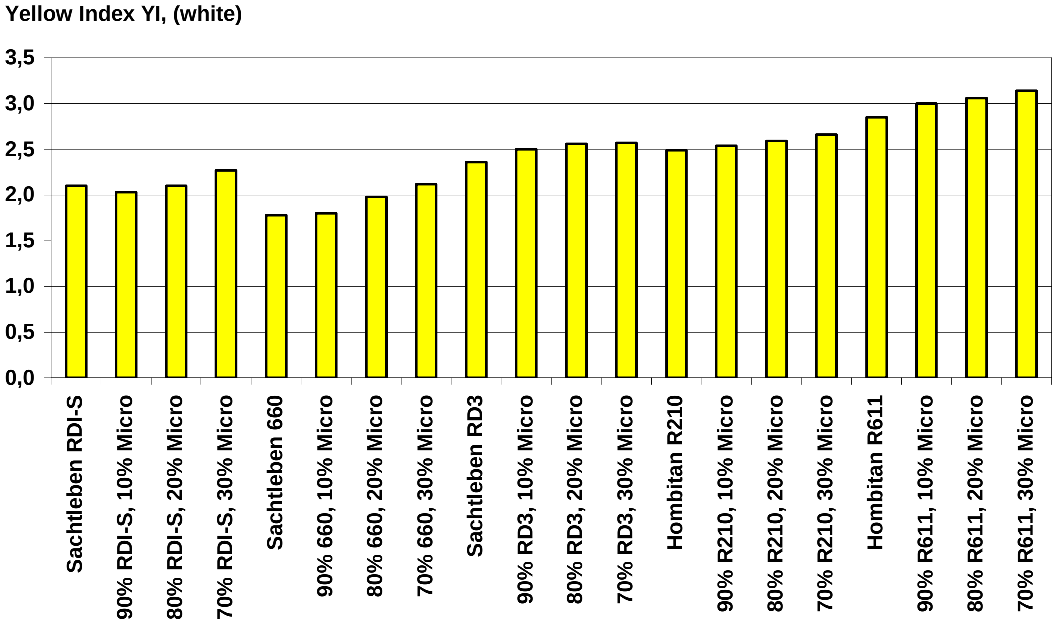

Figure 2. Yellow index YI of white solvent borne paint when five different pigments with Sachtleben Micro are used.

Effect of titanium dioxide grade on properties of white solvent borne paint

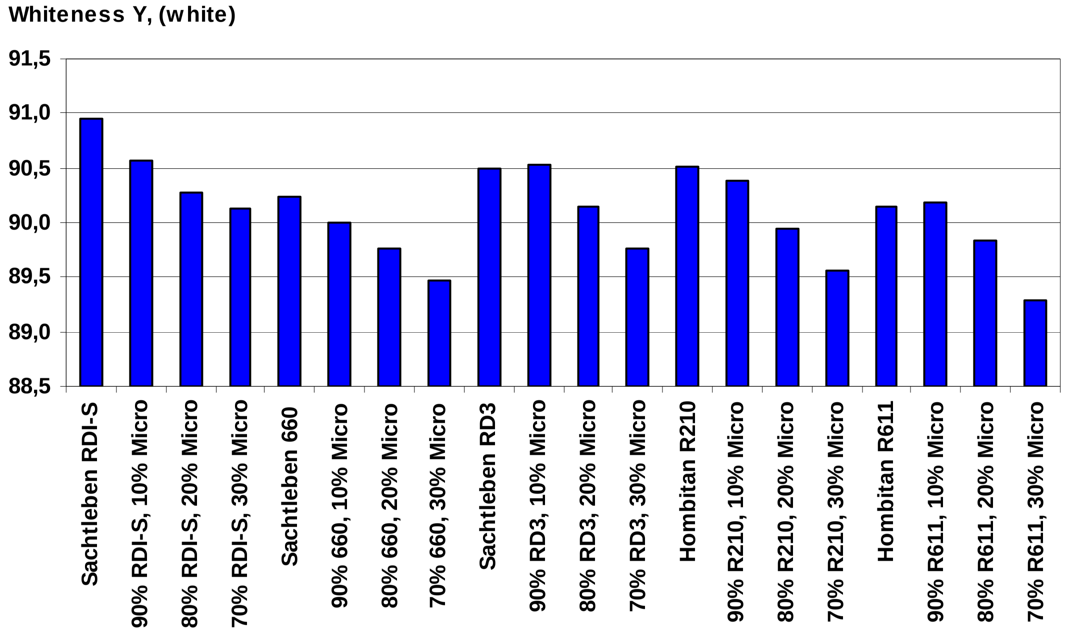

Figure 3. Whiteness Y of white solvent borne paint when five different pigments with Sachtleben Micro are used.

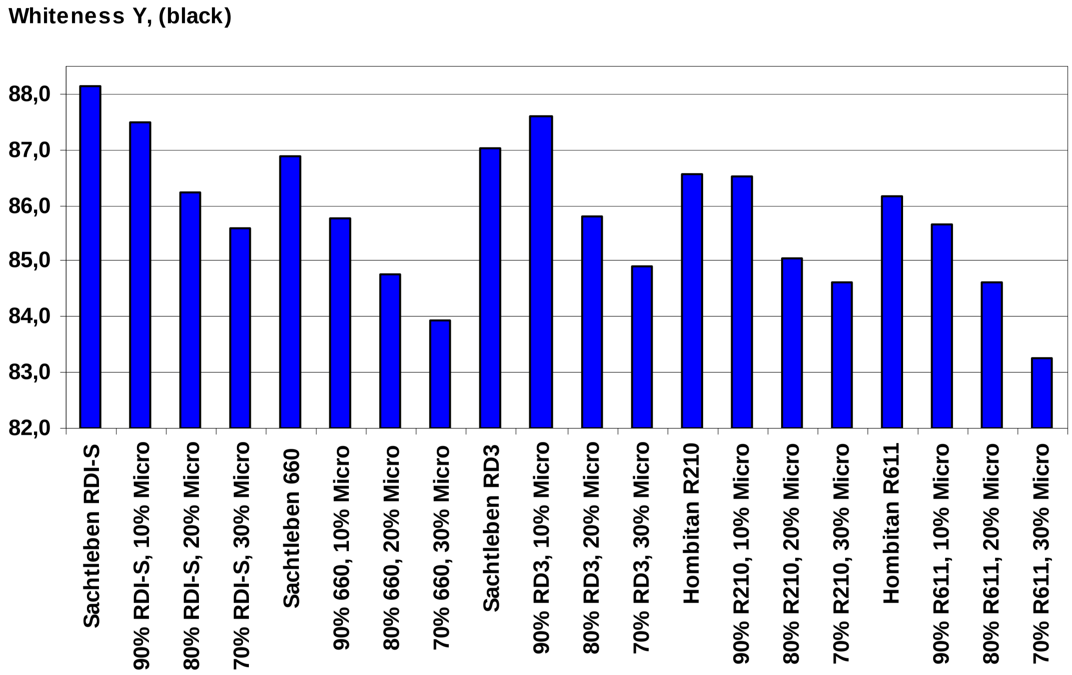

Figure 4. Whiteness Y of white solvent borne paint on black backing when five different pigments with Sachtleben Micro are used.

Effect of titanium dioxide grade on properties of white solvent borne paint

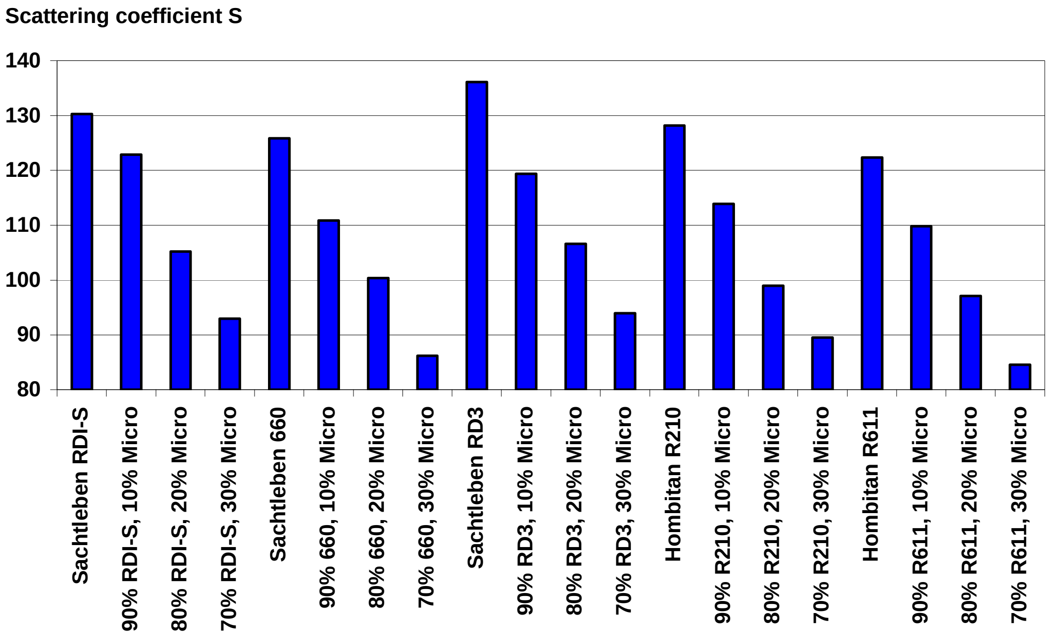

Figure 5. Scattering coefficient S of white solvent borne paint when five different pigments with Sachtleben Micro are used.

Effect of titanium dioxide grade on properties of grey solvent borne paint

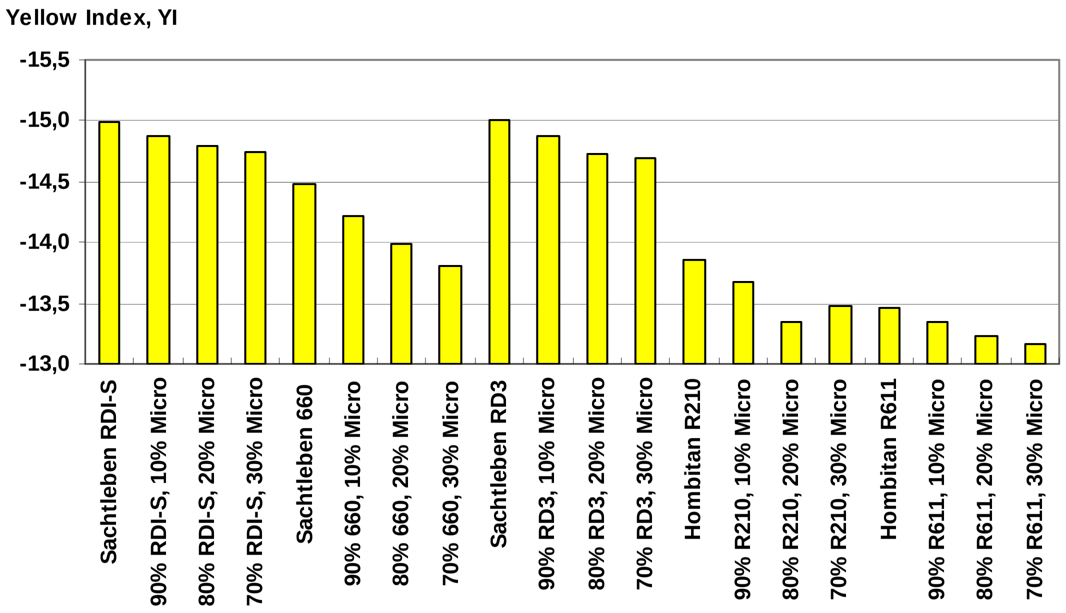

Figure 1. Yellow index YI of grey solvent borne paint when five different pigments with Sachtleben Micro are used.

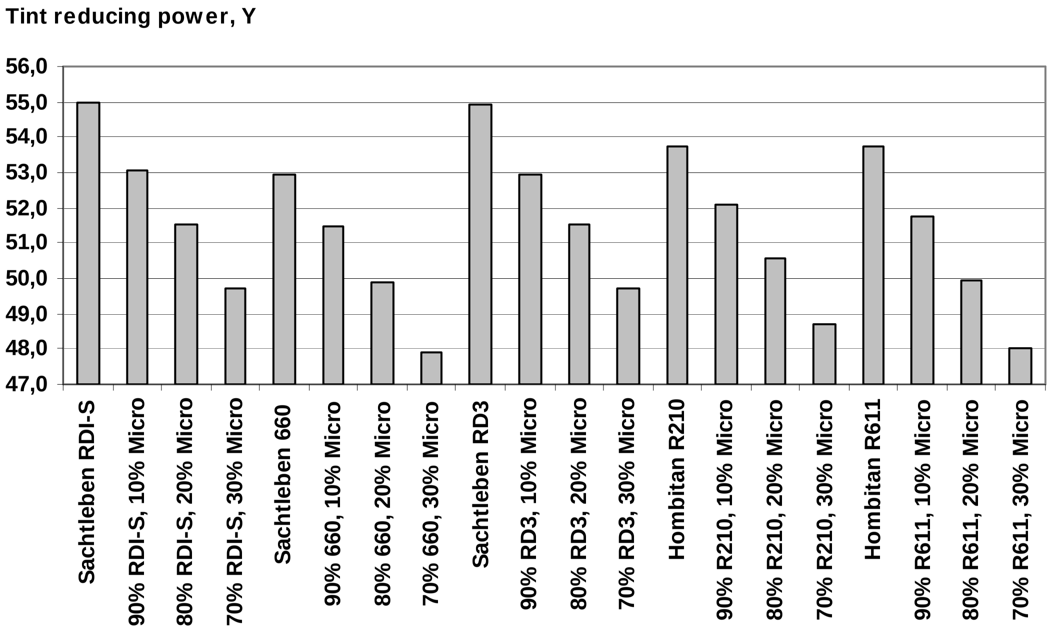

Figure 2. Tint reducing power Y of grey solvent borne paint when five different pigments with Sachtleben Micro are used.

Effect of titanium dioxide grade on properties of water-borne paint

Table 1. Grinding temperatures.

		T/℃
1	Sachtleben RDI-S	42,7
2	90% RDI-S+ 10% Sachtleben Micro	41,3
3	80% RDI-S+ 20% Sachtleben Micro	39,5
4	70% RDI-S+ 30% Sachtleben Micro	38,5
5	Sachtleben 660	44,0
6	90% 660+ 10% Sachtleben Micro	43,2
7	80% 660+ 20% Sachtleben Micro	42,1
8	70% 660+ 30% Sachtleben Micro	41,1
9	Sachtleben RD3	42,9
10	90 % RD3+ 10% Sachtleben Micro	40,7
11	80 % RD3+ 20% Sachtleben Micro	38,8
12	70 % RD3+ 30% Sachtleben Micro	38,0
13	Hombitan R210	44,5
14	90% R210+ 10% Sachtleben Micro	43,1
15	80% R210+ 20% Sachtleben Micro	44,6
16	70% R210+ 30% Sachtleben Micro	42,8
17	Hombitan R611	43,1
18	90% R611+ 10% Sachtleben Micro	41,1
19	80% R611+ 20% Sachtleben Micro	41,6
20	70% R611+ 30% Sachtleben Micro	44,5

Effect of titanium dioxide grade on properties of water-borne paint

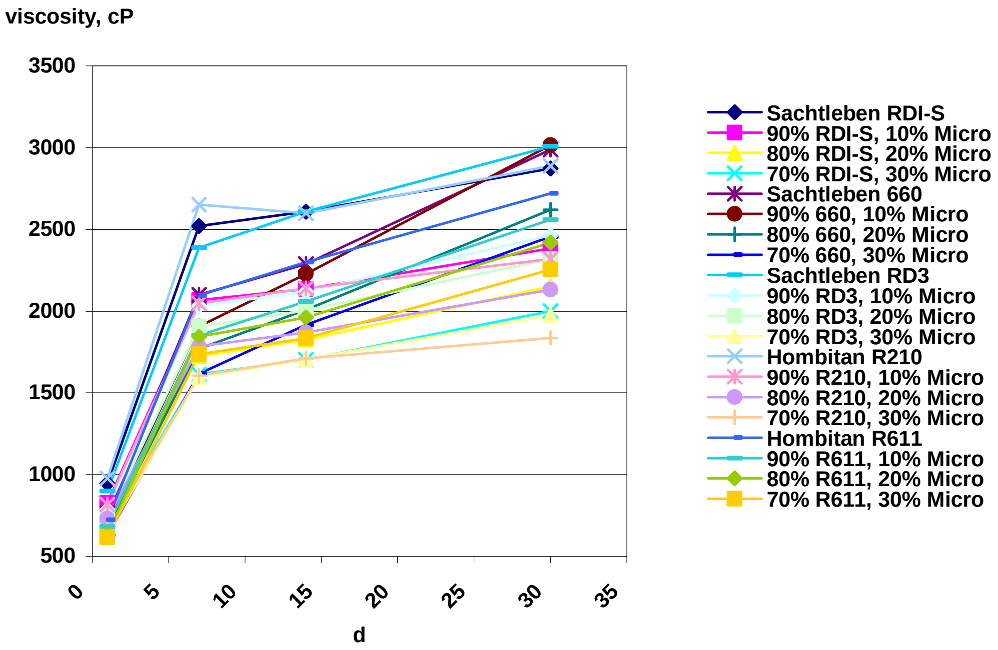

Figure 1. Viscosity of white water-borne paint when five different pigments with Sachtleben Micro are used.

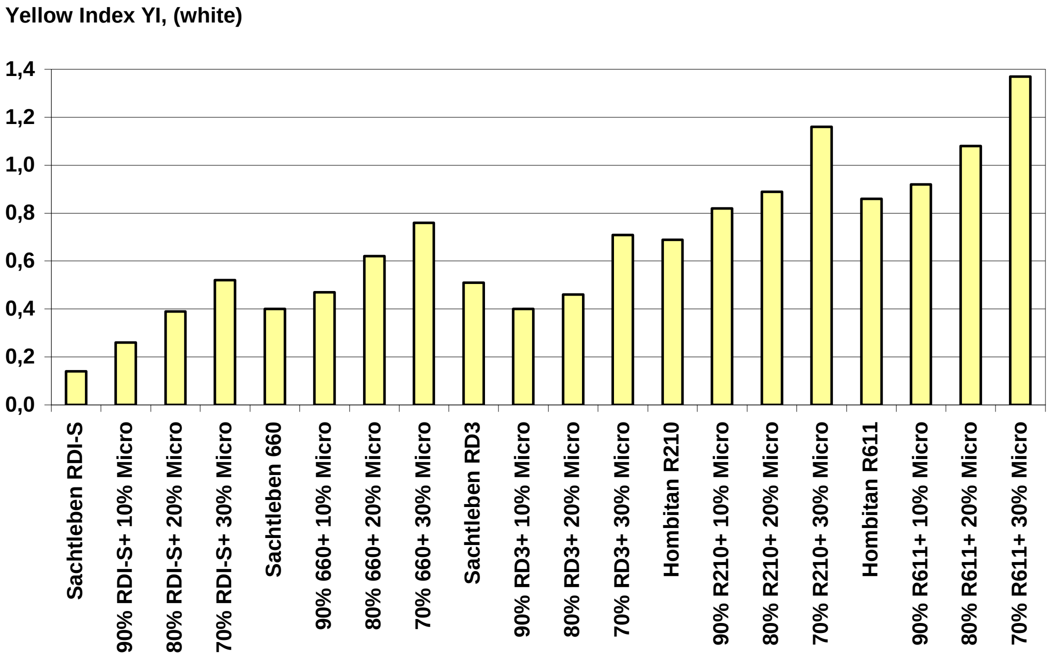

Figure 2. Yellow index YI of white water-borne paint when five different pigments with Sachtleben Micro are used.

Effect of titanium dioxide grade on properties of water-borne paint

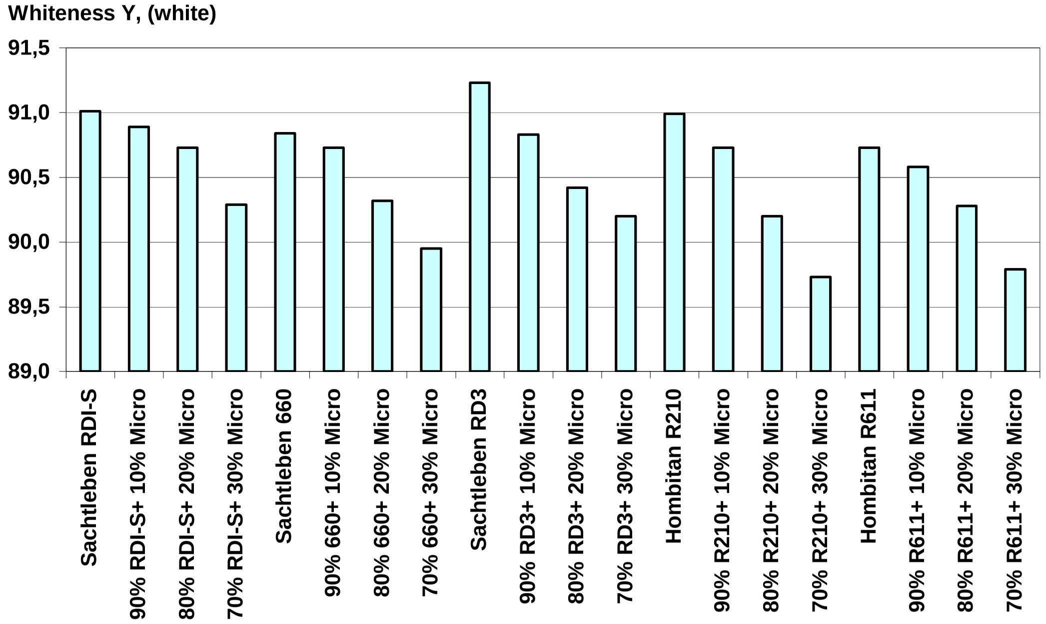

Figure 3. Whiteness Y of white water-borne paint when five different pigments with Sachtleben Micro are used.

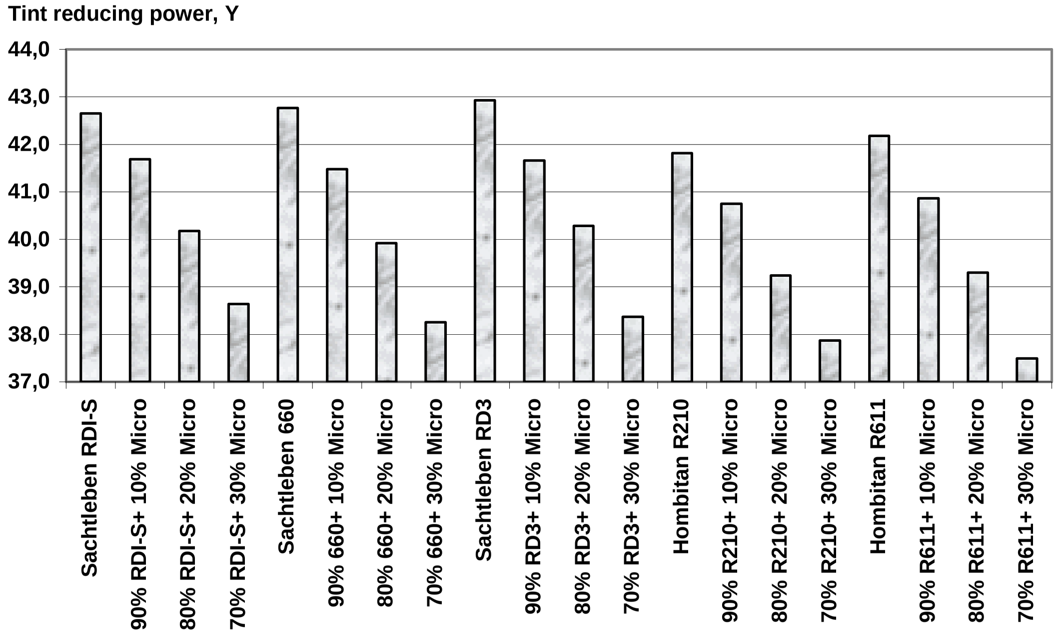

Figure 4. Tint reducing power Y of grey water-borne paint when five different pigments with Sachtleben Micro are used.

Effect of titanium dioxide grade on properties of water-borne paint

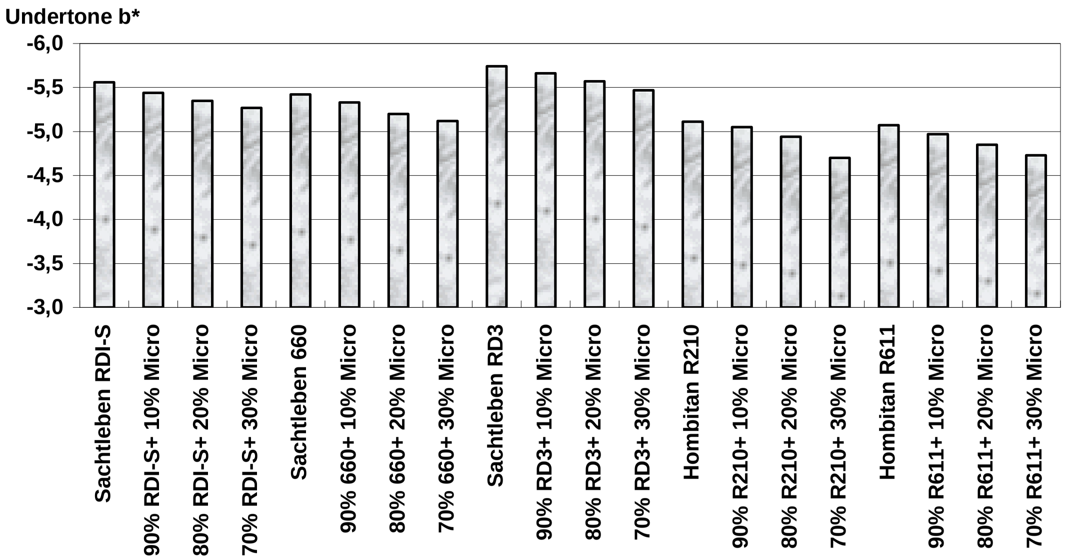

Figure 5. Undertone b* of grey water-borne paint when five different pigments with Sachtleben Micro are used.

Comparison of performance of mechanical mixtures of filler and titanium dioxide to performance of Sachtleben K40 in white solvent borne paints

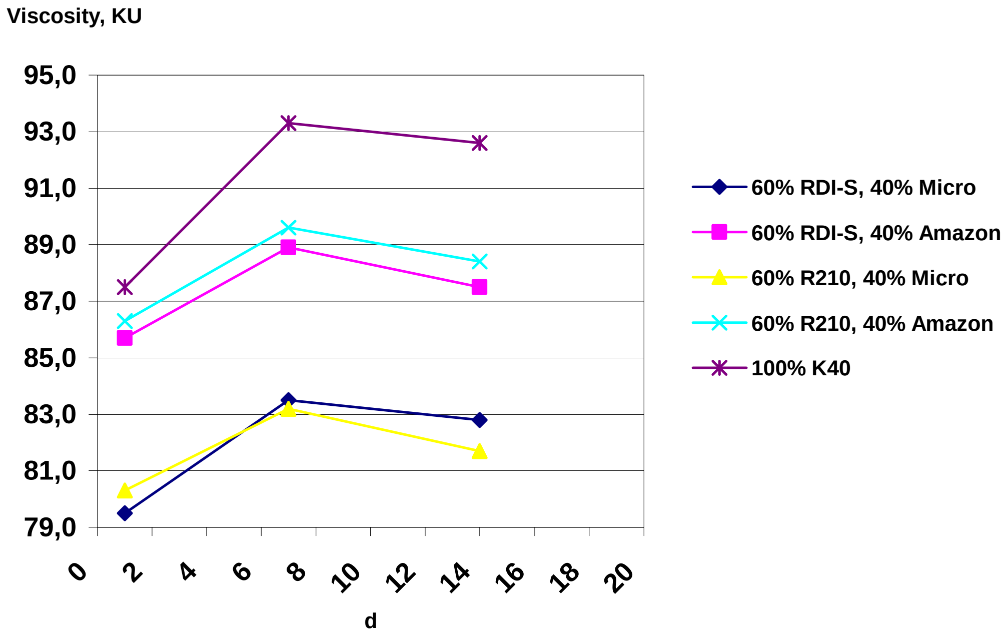

Figure 1. Viscosity of white solvent borne paint with K40, RDI-S or R210 and 40 % of Micro or Amazon.

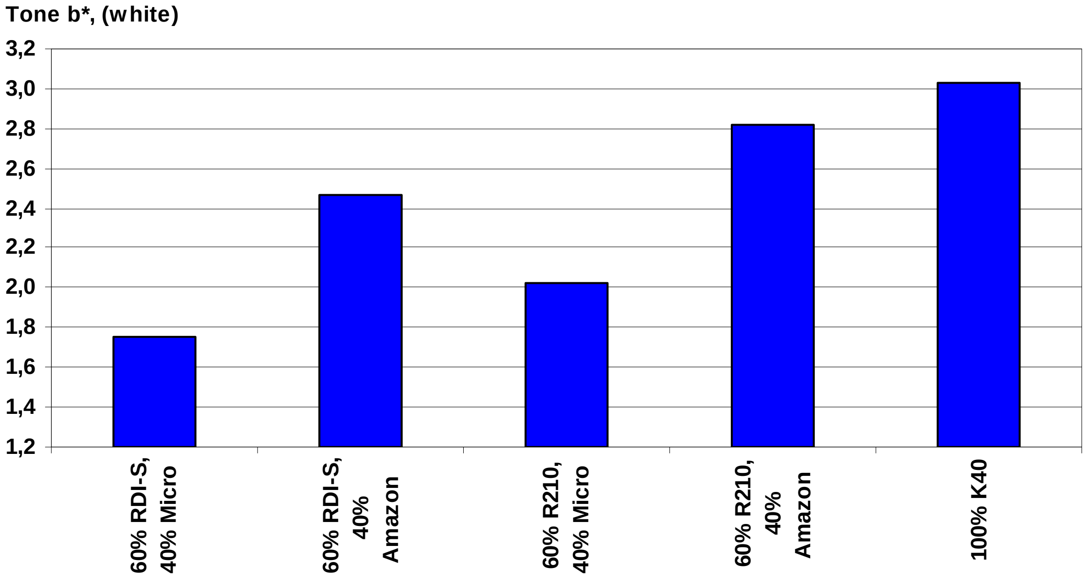

Figure 2. Tone b* of white solvent borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

Comparison of performance of mechanical mixtures of filler and titanium dioxide to performance of Sachtleben K40 in white solvent borne paints

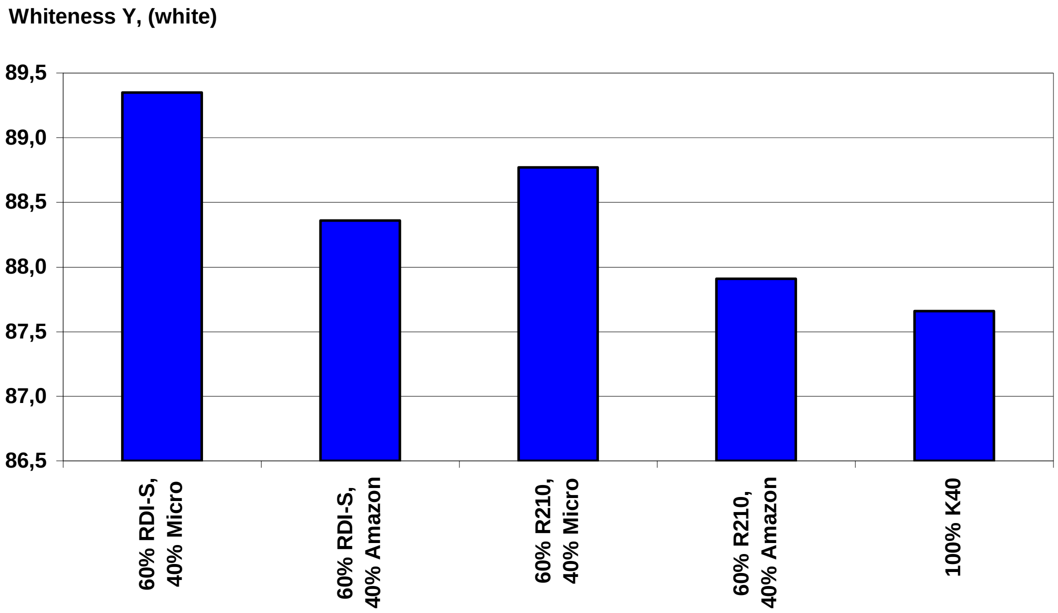

Figure 3. Whiteness Y of white solvent borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

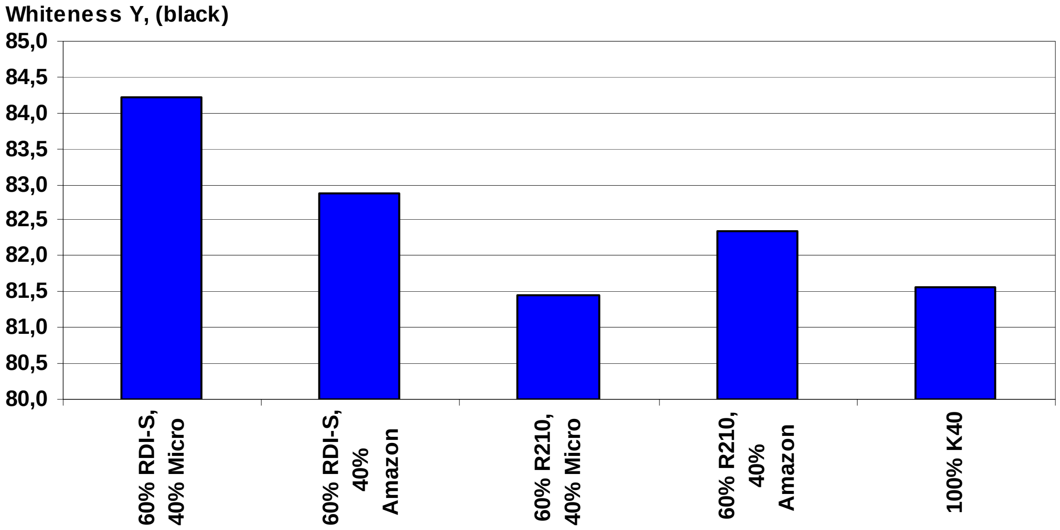

Figure 4. Whiteness Y of white solvent borne paint on black backing with K40, RDI-S or R210 and 40% of Micro or Amazon.

Comparison of performance of mechanical mixtures of filler and titanium dioxide to performance of Sachtleben K40 in white solvent borne paints

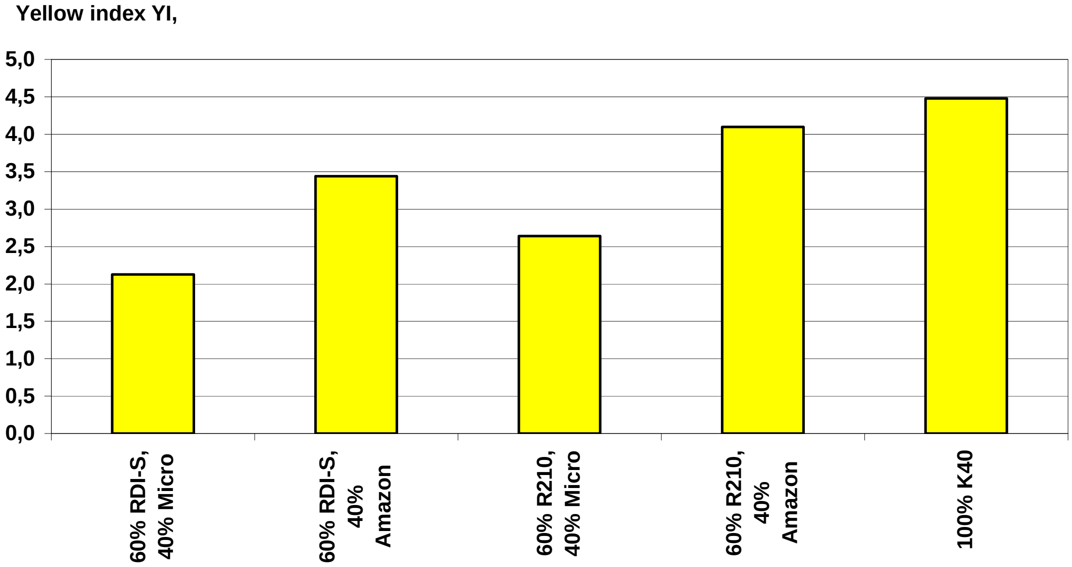

Figure 5. Yellow index YI of white solvent borne paint on black backing with K40, RDI-S or R210 and 40% of Micro or Amazon.

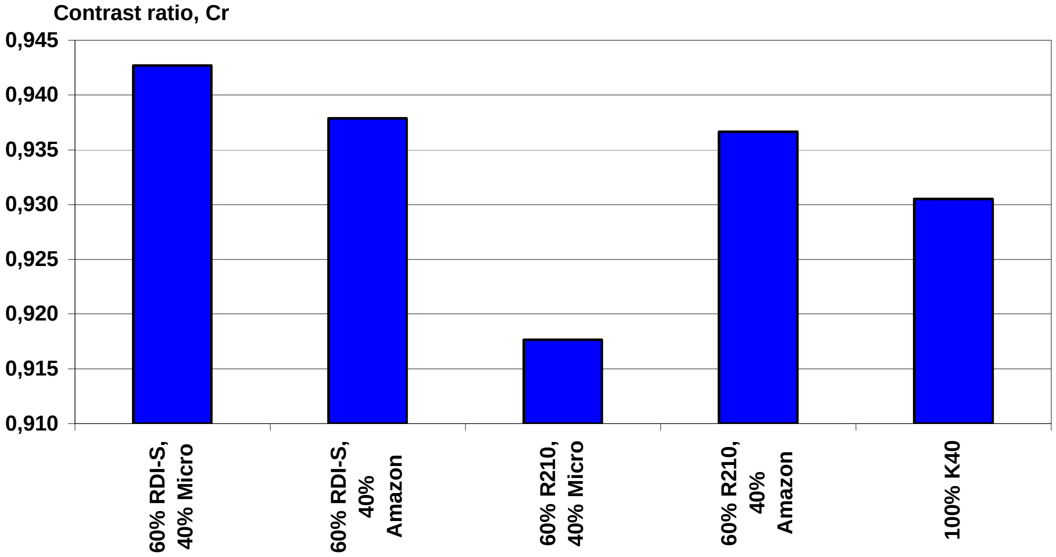

Figure 6. Contrast ratio Cr of white solvent borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

Comparison of performance of mechanical mixtures of filler and titanium dioxide to performance of Sachtleben K40 in grey solvent borne paints

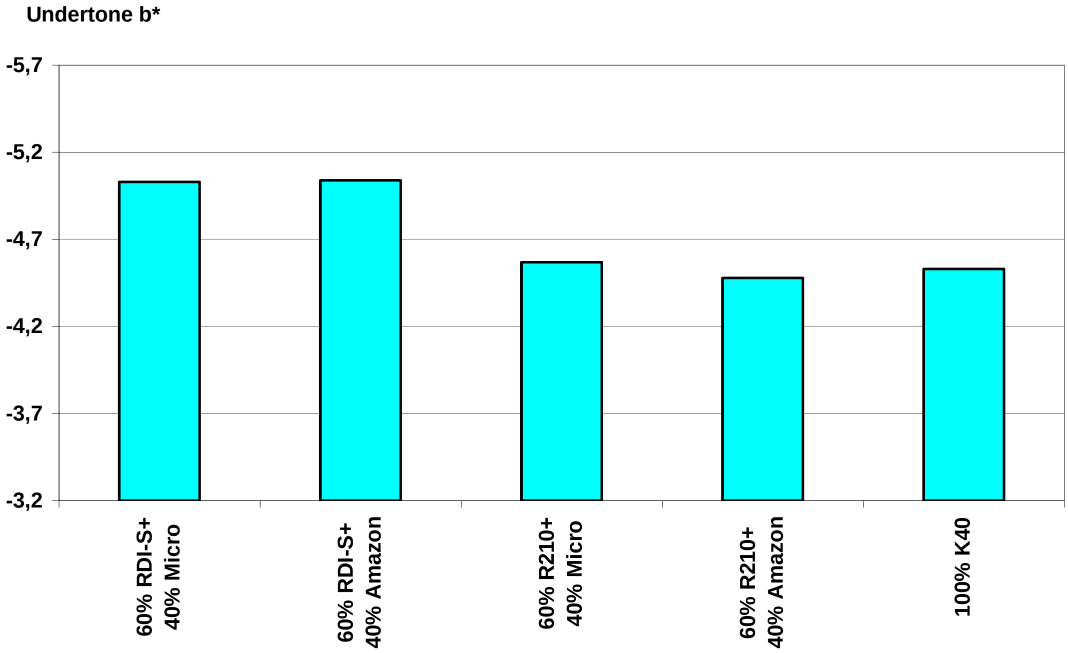

Figure 1. Undertone b* of grey solvent borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

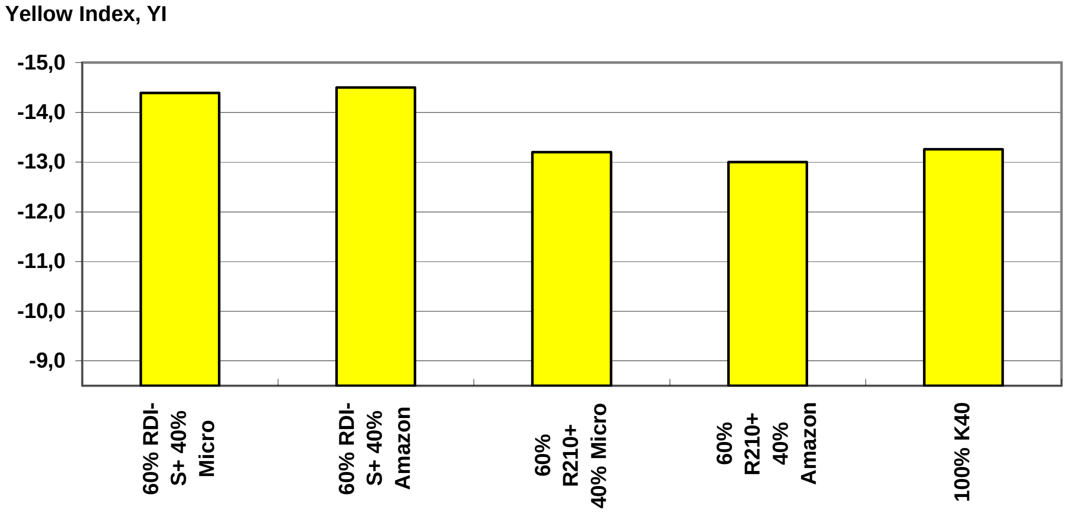

Figure 2. Yellow index YI of grey solvent borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

Comparison of performance of mechanical mixtures of filler and titanium dioxide to performance of Sachtleben K40 in grey solvent borne paints

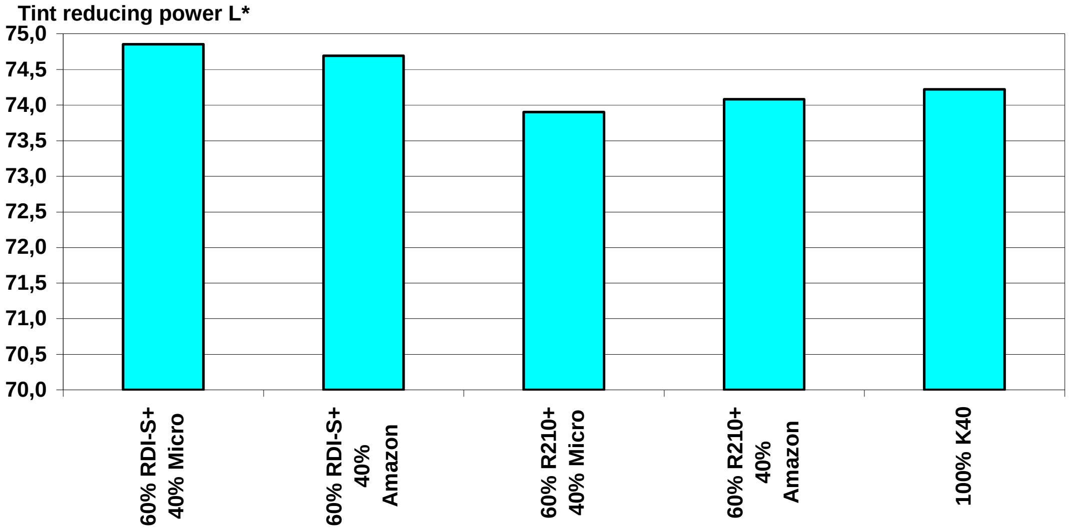

Figure 3. Tint reducing power L* of grey solvent borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

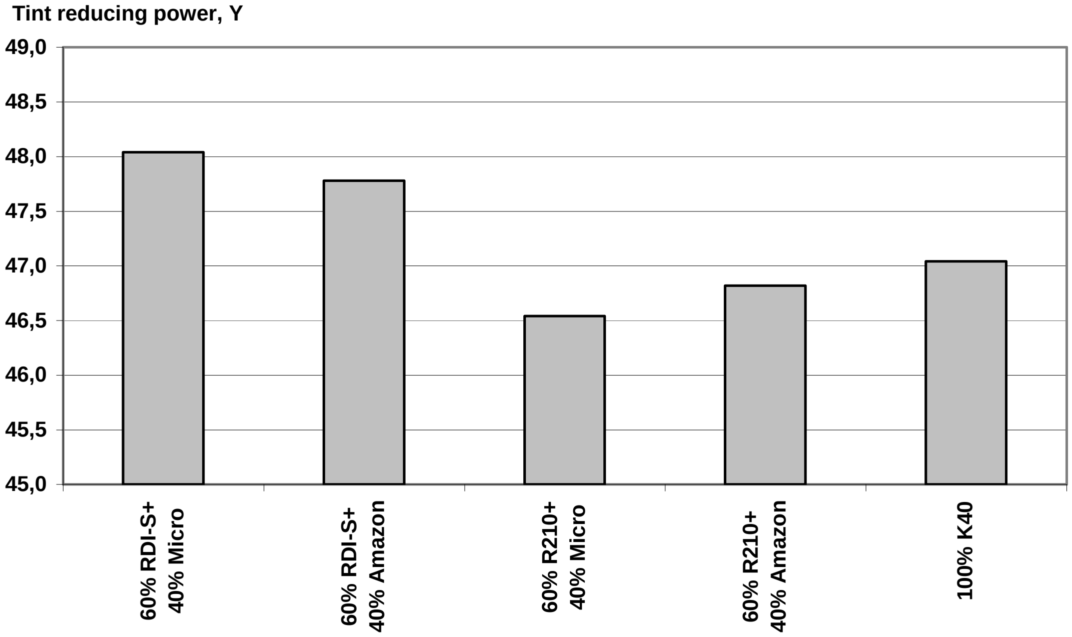

Figure 4. Tint reducing power Y of grey solvent borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

Comparison of performance of mechanical mixtures of filler and titanium dioxide to performance of Sachtleben K40 in water-borne paints

Table 1. Grinding temperatures.

		T/℃
1	**60% RDI-S+ 40% Sachtleben Micro**	37,9
2	**60% RDI-S+ 40% Amazon**	95,5
3	**60% R210+ 40% Sachtleben Micro**	42,5
4	**60% R210+ 40% Amazon**	86,6
5	**K40**	74,0

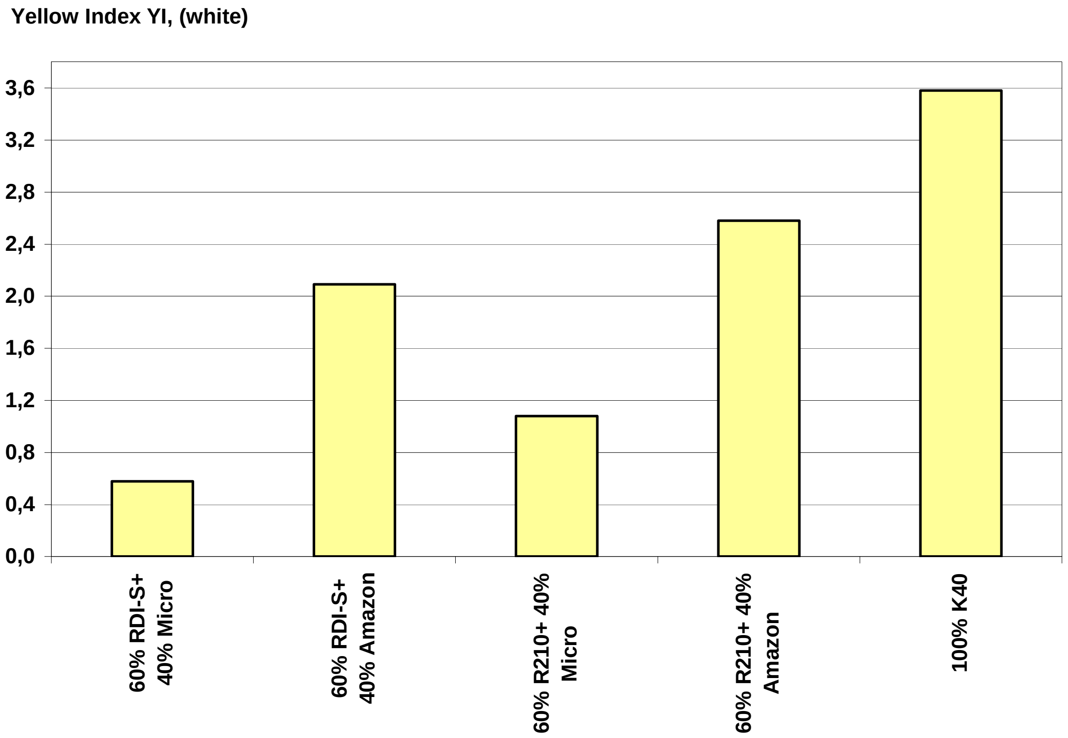

Figure 1. Yellow index YI of white water-borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

Comparison of performance of mechanical mixtures of filler and titanium dioxide to performance of Sachtleben K40 in water-borne paints

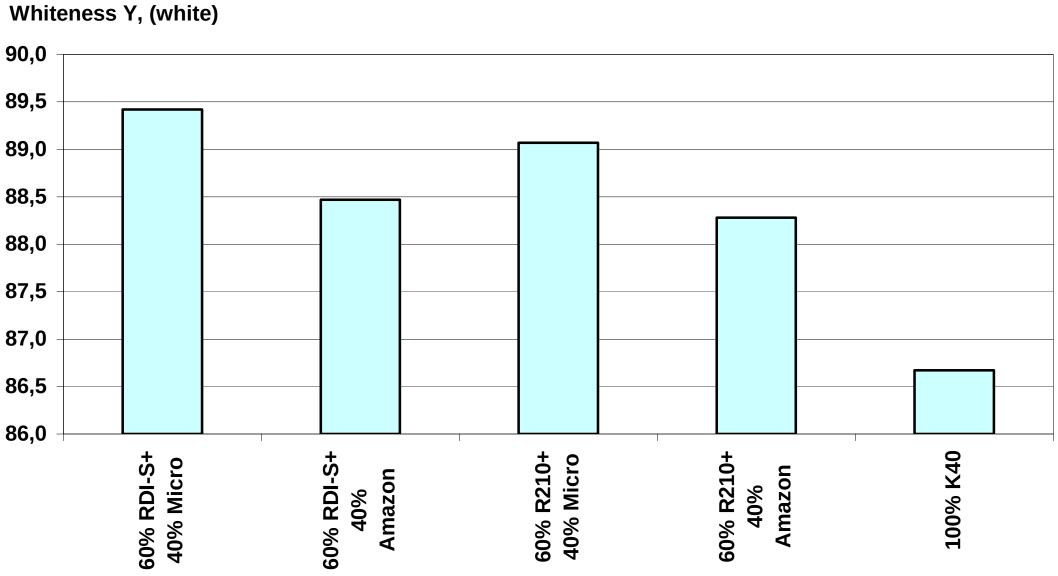

Figure 2. Whiteness Y of white water-borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.

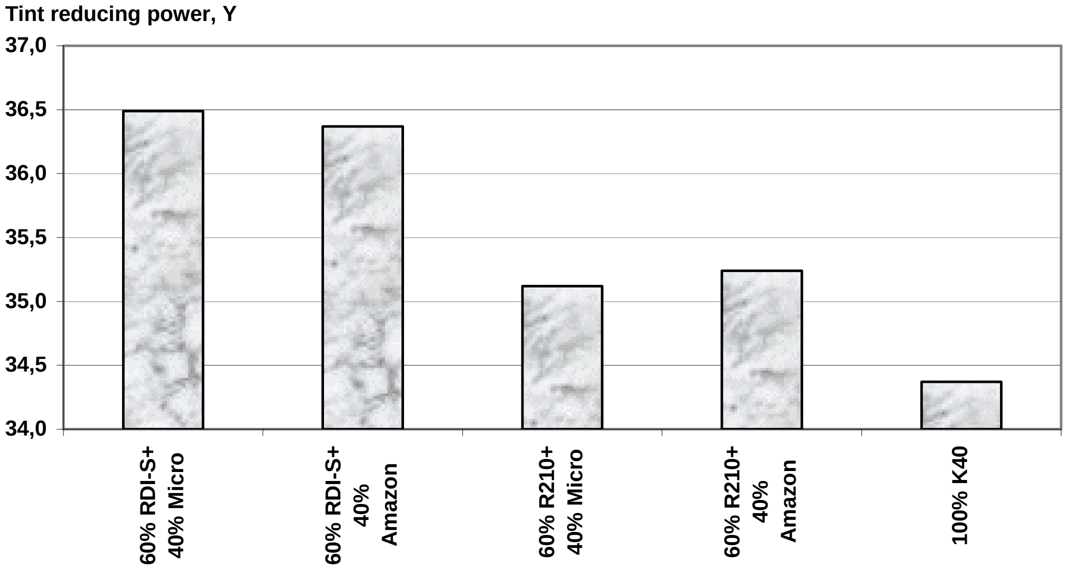

Figure 3. Tint reducing power Y of grey water-borne paint with K40, RDI-S or R210 and 40% of Micro or Amazon.