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Implementation of the process by slurry and concentrate of pigments in latex-type paint formulas. Challenges and opportunities for planning

Implementación del proceso vía slurry y concentrado de pigmentos en fórmulas de pintura tipo látex. Desafíos y oportunidades para la planificación

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Abstract

Changes in product production are limited by high costs in infrastructure, procedures, reformulations and / or substitution of raw materials. Therefore, it is necessary to develop and innovate technologies that minimize impacts, without damaging product quality standards. In paint formulations, the dispersion process is of vital importance, which is why this research evaluated the possibility of implementing the technique slurry and pigment concentrate in the traditional way of manufacturing latex-type paints of the premium line (satin and exterior), and partially eliminate the dispersion stage, maintaining the physicochemical characteristics according to Venezuelan COVENIN standards. For this, three types of slurries were used; I: Aqueous dispersion of calcium carbonate ($CaCO_3$), magnesium silicate ($MgSiO_3$) and Kaolin ($Al_2Si_2O_5(OH)_4$), II: Aqueous dispersion of $CaCO_3$, III: Aqueous dispersion of $CaCO_3$ and Kaolin. Likewise, in the pigment concentrates, two types of aqueous dispersion of titanium dioxide (TiO_2) of medium and high dispersibility were used. As a result, there were no significant variations in terms of the quality characteristics of the paints obtained through the process by slurry and pigment concentrate with respect to the traditional manufacturing process. In addition, a reduction of 102 minutes was achieved on the global manufacturing time, since the previous dispersion of the pigments and extenders present in the pigment concentrates and slurries was used, thus eliminating one of the four stages of the manufacturing process of the lines (scattering stage). With the use of slurries and pigment concentrates, it was possible to increase productivity by 31.20 %, becoming an alternative for paint manufacturers, without investing in new equipment.

Keywords: slurry; pigments; pigment concentrate; latex paint; satin paint; matte paint; dispersion; titanium dioxide; reformulation; norma COVENIN.

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Resumen

Los cambios en la producción de productos se ven limitadas por los altos costos en infraestructura, procedimientos, reformulaciones y/o sustitución de materias primas. Por ello, resulta necesario desarrollar e innovar tecnologías que minimicen los impactos, sin perjudicar los estándares de calidad del producto. En las formulaciones de pinturas el proceso de dispersión es de vital importancia por lo que la investigación evaluó la posibilidad de implementar la técnica vía slurry y concentrado de pigmentos en el proceso vía tradicional de fabricación de pinturas tipo látex de la línea premium (satinada y exterior) y eliminar parcialmente la etapa de dispersión, manteniendo las características fisicoquímicas de acuerdo con las normas venezolanas COVENIN. Para ello se usaron tres tipos de slurrys; I: Dispersión acuosa de Carbonato de calcio ($CaCO_3$), silicato de magnesio ($MgSiO_3$) y Caolín ($Al_2Si_2O_5(OH)_4$), II: Dispersión acuosa de $CaCO_3$, III: Dispersión acuosa de $CaCO_3$ y Caolín. Asimismo, en los concentrados de pigmentos se utilizó dos tipos de dispersión acuosa de dióxido de titanio (TiO_2) de mediana y alta dispersabilidad. Como resultado se observó que no hubo variaciones significativas en cuanto a las características de calidad de las pinturas obtenidas mediante el proceso vía slurry y concentrado de pigmento con respecto al proceso de fabricación vía tradicional. Además, se alcanzó una disminución de 102 minutos sobre el tiempo global de fabricación, ya que se aprovechó la previa dispersión de los pigmentos y extenders presentes en los concentrados de pigmentos y slurrys, logrando así eliminar una de las cuatro etapas del proceso de fabricación de las líneas (etapa de dispersión). Con el uso de los slurrys y concentrados de pigmentos se logró incrementar en un 31,20 % de la productividad convirtiéndose en una alternativa para los fabricantes de pinturas, sin realizar una inversión en nuevos equipos.

Palabras clave: slurry; pigmentos; concentrado de pigmento; pintura látex; pintura satina; pintura mate; dispersión; dióxido de titanio; reformulación; Norma COVENIN.

1. Introduction

With scientific advancement in techniques and the prevailing need for sustainable development in countries, there is dynamism in the changes in the environment, there is a vertiginous growth in the market, and an accelerated speed of technological progress, quality requirements, among others, that propose challenges that guarantee a real boost in companies worldwide. That is why developments and innovations in various fields lead to improving the existing conditions for any type of engineering product [1].

Paint technologies have the most part, where any type of change for in the formulation translates into profits. It all depends on the characteristics of paints, the addition relationships, the order of aggregation, dosages of minerals, environmental impact that could improve some physical and mechanical properties [2].

It is important to emphasize that the dispersion process is considered the most important stage in the manufacture of paints, it homogenizes solvents, resins and additives that allow disperse and stabilize the paint, then added with agitation pigments and fillers, the result of this dispersion influences properties such as gloss, uniformity, smoothness of the applied film, hiding power and color strength.

In the search to optimize the process of raw materials aggregates in latex-type paint formulations, the use of the slurry technique is studied, which consists of a concentrated suspension of one or more extensions (sulfates, silicates, carbonates, kaolin, talc, etc. among others), dispersed in an aqueous phase at different granulometries or particle size, which are used in the paper, cable, cosmetic and paint industries, to save raw material costs [3]. In addition, the slurry technique constitutes an economical, ecological, effective, and efficient solution in paint formulation processes.

Pigments are fine crystalline substances with a refractive index greater than 1.7 of a defined color, whose use is aimed at defining the color tone of the finished product [4]. Among them, titanium dioxide (TiO_2) stands out, which is used in a wide variety of domestic and industrial applications and is becoming an increasingly valuable nanomaterial [5], [2].

The formulation of paints significantly influence the use of this pigment, since it is expensive, which is why the mass production of most companies is limited, arousing interest in research in terms of products reformulation and implementation of new technologies, without affecting product quality standards [6].

Often extenders are included which are lamellar or acicular structures whose function is to improve the performance and optimize the distribution of TiO_2 in such a way that it contributes with a beneficial optical coverage of the surface [7], [4], [8], among them are mica, kaolin and talc.

Extenders are compatible with various binder chemistries, therefore, if extenders can be dispersed efficiently, they will not affect the choice of binder. However, this substitution depends on the selection criteria such as the particle size distribution, particle size, shape, surface area, oil absorption rate, whiteness, weatherability, as they significantly affect the quality of the paints in terms of stability, hiding (opacity), gloss, scrub resistance (film toughness), among others.

The effect of calcined kaolin and calcite as an extender and substitute in part for TiO_2 show better physical properties, especially because the mineral particles fill the gaps between the TiO_2 particles and keep them separated through physical interactions [4], [5], [6], [9].

Although it is possible to perform direct placement of TiO_2 by a synthetic opaque pigment, the new trends prefer this replacement by performing some new methods of preparation of pigment particles and extenders for painting [7].

An important criterion for developing the paint formula, especially for architectural paints, is to add the maximum amounts of mineral pigments, extenders, and fillers as much as possible to satisfy the rheology of the paint. The proper type and amount of dispersants are crucial at this stage to obtain the proper adequate flowability for a large amount of pigment and fillers [10].

Further research should focus on optimizing the amount and type of minerals in paint formulations and reformulations considering both surface chemistry and desired paint properties [9], [11].

This work consisted of evaluating the real behavior of latex-type paint formulas of the premium line (satin and matte exterior) elaborated by traditional means, with the intention of implementing the slurry technique and pigment concentrate in one of the manufacturing stages, in order to reduce production time (man-hours), innovating technologies that minimize environmental impacts, without harming the quality standards of the paint. For this purpose, the physical, mechanical, chemical, performance and quality behavior of the paints is analyzed following the test methods reflected in the Venezuelan COVENION Norms [6].

The knowledge gained from this study allows the development of design rules for latex-type paint formulations and the implementation of the process by slurry and pigment concentrate.

2. Materials and methods

2.1. Manufacture of the types of slurry and pigment concentrate to be used according to the characteristics of the satin and matte exterior paints

Table 1 shows the types and components of slurry and pigment concentrate, for which the physical and chemical properties of each paint were taken into consideration.

Table 1. Type of slurry and pigment concentrate to use according to the characteristics of the paints

Characteristics	Components
Slurry I	Aqueous dispersion of $CaCO_3$, $MgSiO_3$ and $Al_2Si_2O_5(OH)_4$
Slurry II	Aqueous dispersion of $CaCO_3$
Slurry III	Aqueous dispersion of $CaCO_3$ and kaolín
Pigment concentrate I	Aqueous dispersion of TiO_2 of medium dispersibility
Pigment concentrate II	Aqueous dispersion of TiO_2 of high dispersibility

*$CaCO_3$: Calcium carbonate; $MgSiO_3$: Magnesium Silicate; Kaolin: ($Al_2Si_2O_5$ (OH) $_4$); TiO_2: Titanium dioxide

2.2. Selection of the type of slurry for satin paint

Fillers and extenders do not impart color like pigments, the main role they play is to increase the volume of the paint. They also improve properties such as abrasion resistance, permeability and gloss [4], [5], [6], [9], [10], [11], [12].

For the selection of the type of slurry, the main variables considered were the hiding power, the gloss, and the whiteness of the applied film, which are very sensitive to the influence of loads and extenders.

As it is a paint with a shiny and silky finish, type III slurry was selected; its properties give it a characteristic shine. The Table 2 shows the raw materials for making the slurry.

Table 2. Slurry type III aqueous dispersion of calcium carbonate and kaolin

Components	Mass (%)
Treated water	10-40
Viscosity modifier	0.1-1.5
Defoamer	0.05-2.5
Dispersant	0.1-2.5
Moisturizer	0.1-2.5
Kaolin	**17.65**
Calcium carbonate	**43.14**
Coalescent	0.05-2.5
Artificial fragrance	0.05-2.5
Treated water	0.305
Bactericide	0.03-2.5
Fungicide	0.01-1.5
Treated water	5.158
Defoamer	0.01-1.5
Total	100.00

*$CaCO_3$: Calcium carbonate; Kaolin: ($Al_2Si_2O_5(OH)_4$)

2.3. Selection of pigment concentrate for satin paint

As for the selection of the pigment concentrate, the type II concentrate presented in Table 3 was chosen.

Table 3. Pigment concentrates type II, aqueous dispersion of highly dispersible aqueous titanium dioxide

Components	Mass (%)
Treated water	10-40
Viscosity modifier	0.01-2.5
Defoamer	0.01-2.5
Dispersant	0.01-2.5
Moisturizer	0.01-1.5
Solvent	0.5-3.5
High dispersibility titanium dioxide	**69.79**
Treated water	10-30
Defoamer	0.01-1.5
Bactericide	0.03-2.5
Total	100.00

It has suitable characteristics for the satin line; it is an aqueous dispersion highly dispersibility titanium dioxide, with a mass percentage of 69.79%.

Among the characteristics it brings to the paint, are: a great covering power, excellent whiteness, high dispersibility and a very small particle size (silky finish), which is ideal for the brightness of this line, it should be noted that this concentrate is formed the TiO_2 present in the original formula of the satin paint.

2.4. Selection of type of slurry matte exterior paint

Table 4 shows slurry type I, an aqueous dispersion of calcium carbonate, magnesium silicate and kaolin, with a mass percentage of 43.82%, 3.24% and 13.69% respectively. The physicochemical characteristics of $CaCO_3$ and $MgSiO_3$ improve the hiding power and have a high resistance to weathering, in paints for facades; finally, kaolin increases the viscosity and covering power of the paint.

In addition, characteristics such as the type of filler, particle size, whiteness percentage, and yellowness index were taken into consideration. It is important to consider that slurry I was used in synergy with slurry III in order to meet the product quality requirements. As for the pigment concentrate, type II was used.

The composition of each of the formulas elaborated by traditional means is maintained, each component is incorporated in proportion through the slurries manufactured previously.

The manufactured paints have an associated specification sheet, as established in the Venezuelan COVENIN Norms, which indicate the physicochemical properties of interest and the allowed values [6], [13].

2.5. Formulation, manufacturing, product design and physicochemical properties

Through the traditional manufacturing process, the following stages are present: dispersion, finishing, adjustment and quality control, while in the process way slurry and pigment concentrate, only the dispersion stage was eliminated and the others are maintained. For the formulation of the white color paints developed way slurry and pigment concentrate, we proceeded to perform the mixing: type of slurry, pigment concentrate selected according to the type of paint with the rest of the components of the termination stage which are: defoamers, dispersants, bactericides, fungicides, resin, coalescers, among others, with a strict order and weighing.

Finally, the physicochemical properties were evaluated comparing them with the white paints obtained by the traditional method that includes the dispersion stage, while in the paints made by slurry and pigment concentrate the dispersion stage is eliminated. Table 5 specifies the characteristics determined, said assessment was made taking into consideration the quality tests established in the Venezuelan COVENIN Standards [13]. The reproducibility of the manufacturing process via slurry and pigment concentrate in the production of the paints (satin and matte exterior) were verified.

3. Results

3.1. Analysis of the satin paint formulation way slurry and pigment concentrate

Table 6 shows the raw materials that made up the formula; the type III slurry provided adequate characteristics to the paint, which were of a silky finish, allowed a smooth, sealed and resistant surface to harmful effects [4], it developed a semi-bright white color since it contains the main charge of the original formula 43.14% by mass of $CaCO_3$ and 17.65% by mass of ($Al_2Si_2O_5$ $(OH)_4$) (see Table 2), $CaCO_3$ improved the covering power because it has a high oil absorption, giving a high structure to the paint (thixotropy), also, as it has a high refractive index, the pigment will be less transparent and therefore, more covering [9], [27], [28], [29].

Also, type III slurry maintained the viscosity values according to its specification and the percentage of whiteness of the applied film, without affecting the gloss, thus helping to reduce costs associated with the use of pigment such as TiO_2 resent in type II pigment concentrate (aqueous dispersion of TiO_2 of highly dispersibility), which provided a higher hiding power, characteristic gloss without imperfections on the surface and a better resistance in the paint. Likewise, $CaCO_3$ had a small average particle size that was similar to the particle size of TiO_2, so the dispersion effect was favorable [6].

This fact agrees with Yang et al., in their research it was found that the groups of TiO_2 particles clusters in the cured paint film can be reduced and the quasi-liquid phases or voids in the coating, likewise, the demand for TiO_2 particles decreases [30]. In this way, it contributes to reduce the manufacturing cost of the paint, and improves the physical and chemical performance of the cured paint. It is important to note that slurry I was not selected, because it contains magnesium silicate affecting the gloss negatively [4], [9], [10].

Table 4. Slurry type I. Aqueous dispersion of calcium carbonate, magnesium silicate and kaolin

Components	**Mass (%)**
Treated water	10-30
Viscosity modifier	0.1-1.5
Defoamer	0.1-1.5
Dispersant	0.3-1.5
Humectante	0.1-1.2
kaolín	**13.69**
Magnesium Silicate	**3.24**
Calcium carbonate	**43.82**
Coalescent	0.8-2
Artificial fragrance	0.01-1
Treated water	0.2-.,5
Bactericide	0.05-2.5
Fungicide	0.01-1.5
Treated water	1-10
Defoamer	0.01-2.5
Total	**100.00**

*$CaCO_3$: Carbonato de calcio; $MgSiO_3$: Silicato de Magnesio; Caolín: ($Al_2Si_2O_5(OH)_4$)

3.2. Analysis of the satin paint formulation way slurry and pigment concentrate

Table 7 shows the mass percentage ranges of the raw materials used in the manufacture of the paint. Two types of slurries (I and III) were used, with the objective of achieving synergy and strengthening the physical and chemical properties of the line, since it is intended for facade surfaces, presenting resistance to wear, mechanical abrasion from atmospheric agents (UV rays, ozone) and constant changes in wetting and drying periods.

The main variables considered were the covering power, the percentage of whiteness of the paint film applied and additionally the resistance to abrasion.

Table 5. Properties of the paints satin and matt exterior, white color of the premium line

Property	Unidad	Satin White Especification	Exterior matte white Especification
Non-volatile [14]	%	min. 40	min. 40
pH [15]	U. pH	7.5-9.0	8.5-9.5
Weight per gallon [16]	kg/gal	4.8-5.0	5.2-5.4
Degree of dispersion [17]	µm	25-35	45-50
Viscosity [18]	KU	87-97	87-97
Brushability [19]	N/A	min. easy	min. easy
Scrub resistance [20]	Cycles	min. 300	min. 100
Cracking, 100 mils [21]	N/A	N/A	min. very good
Whiteness	%	N/A	N/A
Yellowness index	N/A	N/A	N/A
Radio contrast [22]	%	min. 95	min. 96.5
Fingerprint-free drying [23]	h	max. 1	max. 1
Brightness angle 60 (°) [24]	N/A	15-25	N/A
Stability in the container [25]	N/A	Pass	Pass
Degree of sedimentation [26]	N/A	max. 6	max. 6

*N/A: not applicable, KU: Krebs-Stormer, mín: minimum, max.: maximum, S/norm: no norm, Adim: Adimensional, U: unit

The types of slurries (I and III) have as main component the ($Al_2Si_2O_5(OH)_4$), its particle is of fine laminar form, has moderate resistance to the exterior, and was used mainly to shade paints and $CaCO_3$, with the difference that the slurry type I, contains $MgSiO_3$, which contributed to resistance to weathering (light, temperature changes and the action of rainwater), and improved adherence to smooth substrates [4], main property of the exterior matte line. In addition, the TiO_2 present in type II pigment concentrate is the same used in the original formulation of this line, providing greater covering power and better resistance to paint.

It is necessary to emphasize that the characteristic brightness of the pigment concentrate type II, did not influence in a great way in this line. When mixed with the rest of the components that conformed the paint, its brightness disappeared in its entirety, contrary to the satin line.

3.3. Analysis of the physicochemical properties of the satin and matte exterior paint obtained using the slurry technique and pigment concentrate in contrast to the traditional manufacturing process

The Table 8 shows the results of the physicochemical analyzes carried out on the slurry and pigment concentrate satin line, showing a similar behavior in terms of properties compared to the traditional paint manufacturing process.

Table 6. General manufacturing formula of the satin paint way slurry and pigment concentrate

Components	Mass (%)
Treated water	4.0-10.0
Viscosity Modifier	0.05-2.0
Defoamer	0.05-2.0
pH stabilizer	1.0-3.0
Artificial fragrance	0.05-4.0
Moisturizer	0.10-3.0
Type II Pigment Concentrate	**15.0-45.0**
Slurry Type III	**8.0-30.0**
Coalescent	0.30-2.0
Bactericide	0.05-1.5
Fungicide	0.05-2.0
Viscosity Modifier	0.10-3.0
Defoamer	0.01-3.0
Modified Acrylic Resin Emulsion	25.0-50.0
Total	**100.00**

Table 7. General manufacturing formula for the exterior matte paint by slurry and pigment concentrate

Components	Mass (%)
Treated water	3.0-6.0
Defoamer	0.20-2.0
pH stabilizer	1.0-3.0
Solvent	0.20-1.5
Moisturizer	0.01-0.70
Type II Pigment Concentrate	**30.0-60.0**
Slurry Type I	**2.0-10.0**
Slurry Type III	**10.0-30.0**
Treated water	2.0-6.0
Coalescent	0.80-1.6
Bactericide	0.05-5.0
Fungicide	0.50-3.0
Defoamer	0.07-2.0
Viscosity Modifier	0.10-0.80
Modified Acrylic Resin Emulsion	10.0-35.0
Total	**100.00**

It is necessary to emphasize that the gloss property is affected by two characteristics: oil absorption and particle fineness of the extenders used. However, the paint made by slurry and pigment concentrate showed a high gloss of 24.4 with respect to the formula developed by the traditional manufacturing method, because there was a more effective dispersion of fillers, extender and TiO_2 in the slurry and pigment concentrate mixture.

Likewise, the addition of $CaCO_3$ maintained a high brightness, this is manufactured by a controlled milling process that guarantees closed distribution and fine particle size, generating an efficient dispersion and spacing of TiO_2 with minimal affectation of brightness. [31].

In agreement with Karakas et al., in their research they state that introducing kaolin into the paint formulation increases the hiding power and gloss [29]. This means that, in a sense, $CaCO_3$ also has a positive effect on the formulation with a probably similar mechanism. By introducing the third mineral, calcite has improved the opacity and gloss values of the paint compared to TiO_2 and kaolin alone.

At this point, hetero- coagulation between three different mineral particles is expected to occur. This procedure has been observed in various multiphase systems, in all these cases it behaves as single phase [32].

So, the system containing three minerals such as TiO_2, $CaCO_3$ and $Al_2Si_2O_5(OH)_4$ had similar behavior.

Table 9 shows the results obtained from the stability of the formula by slurry and pigment concentrate at room temperature and in the oven at 60°C in an accelerated weathering environment for 7 days, which is equivalent to 60 days of stability. The evaluation of the results of exposure to accelerated weathering was aimed at determining the influence of *UV* light, resistance to chalking, hue change, yellowing in white paints and the loss in satin and gloss paints [4].

When comparing the two formulas, all the properties were maintained within the specification ranges, the viscosity increased to 94 KU in the satin paint elaborated by slurry and pigment concentrate (oven), in comparison with the one obtained at room temperature, however, it does not represent a threat to migrate and start the elaboration of paints by slurry and pigment concentrate because it is maintained within specification being the allowed variation 5 KU.

Table 8. Physicochemical properties of the white paint by slurry and pigment concentrate with respect to the traditional white paint by slurry

Parameters	Satin Paint by Slurry and CP	Satin Paint Traditional method
Viscosity (KU)	89	89
pH	8.51	8.61
Non-Volatile Solids (% m / m)	48.88	49.03
Hiding power (%)	96.84	95.56
Whiteness	89.68	89.32
Yellowness	0.87	0.76
Degree of Dispersion (Micron)	25	25
Scrubbing (Cycles)	454	482
Brightness (º)	24.4	19
Gallon Weight (kg / gal)	4.88	4.87

KU: Krebs-Stormer; (%): percentage; (% m/m): mass /mass percentage; CP: pigment concentrate.

The Table 10 shows the results of the physicochemical analyzes carried out on the exterior matte paint by slurry and pigment concentrate in contrast to those obtained by the traditional manufacturing process, no significant variations were observed, although in terms of coverage, the formula by slurry and pigment concentrate obtained 97.04% with respect to 96.75% achieved by the formula obtained by the traditional method, this is due to the incorporation of pigment concentrate type II and the optimal ratio of slurries type I and type III which provided great hiding power [11].

The percentage of whiteness of the paint film was 88.91 for the formula manufactured by slurry and pigment concentrate compared to 89.69 for the formula manufactured way the traditional method, it should be noted that, although there is a difference, there is no detriment to the properties.

In addition, the whiteness varies according to the brightness and purity of each of the fillers and/or extenders, the favorable effect on this property depends directly on the whiteness of the stone and its production process; whiter extenders generate whiter products when they partially replace TiO_2 [32].

Table 9. Physicochemical properties of the white satin paint by slurry and pigment concentrate after 7 days in stability at room temperature and accelerated furnace stability

Parameters	Satin paint by slurry and CP (Room T.)	Satin paint by slurry and CP (Furnace)
Viscosity (KU)	89	94
pH	8.51	8.33
Non-Volatile Solids (% m / m)	48.88	48.96
Hiding power (%)	96.84	97.22
Whiteness	89.68	89.32
Yellowness	0.87	0.91
Degree of Dispersion (Micron)	25	25
Scrubbing (Cycles)	454	440
Brightness (º)	24.4	23.8
Gallon Weight (kg / gal)	4.88	4.94

T.: temperature; KU: Krebs-Stormer; (%): percentage; (% m / m): mass / mass percentage; CP: pigment concentrate

With the synergy of type I and type III slurries, a slightly yellower shade was observed in the paint film. However, it is not perceptible between the two paint films applied, so no change was made to the formula by slurry and pigment concentrate.

The Table 11 shows the results of the stability of the formula by slurry and pigment concentrate of the exterior matte paint at room temperature and in the oven at 60 °C in an accelerated weathering environment for 7 days, which is equivalent to actual conditions of 60 days in paint stability.

The physicochemical properties remained almost unchanged over time; although, when comparing the viscosity in both formulas, there was an increase in the exterior matte paint way slurry and CP (oven) with a value of 92 KU, however, it does not represent a threat to migrate and implement the development of paints by slurry and pigment concentrate because it remains within specification being the allowed variation of 5 KU.

Table 10. Physicochemical properties of the white exterior matt paint by slurry and pigment concentrate with respect to the white colour obtained by traditional method

Properties	Exterior matte paint by slurry and CP	Matt exterior paint traditional method
Viscosity (KU)	88	87
pH	8.99	9.42
Non-Volatile Solids (% m / m)	54.33	53.64
Hiding power (%)	**97.04**	**96.75**
% Whiteness	88.91	89.69
Yellowness Index	1.02	1.05
Degree of Dispersion (Micron)	45	45
Scrubbing (Cycles)	230	210
Brightness (º)	N/A	N/A
Gallon Weight (kg / gal)	5.35	5.28

%: percentage; (% m / m): mass / mass percentage; KU: Krebs-Stormer; CP: pigment concentrate

3.4. Production plant run of the formulations by slurry and pigment concentrate obtained at the laboratory level

Paint batches of 1000 gallon were made and the time control of each batch of paint product was carried out by comparing the manufacturing times of the two paints. In the traditional manufacturing process, the following stages are present: dispersed, finishing, adjustment and quality control, while in the slurry and pigment concentrate process, the dispersion stage was eliminated and the other stages are maintained. Table 12 shows the results obtained in the production plant for the white color of both paints, by slurry and pigment concentrate.

In satin paint the critical variables that were evaluated were viscosity, hiding power, degree of dispersion and the gloss of the film. No drastic change was evidenced in the physicochemical analysis of the paint. In the case of viscosity, an average value of 93 KU was obtained, being within the allowed range 87-97 KU; the hiding power of the paint did not require adjustment, standing at 96.99%.

Likewise, the degree of dispersion achieved during manufacturing process remained within the desired particle size with a value of 20 microns. Likewise, the gloss of the paint film showed a value of 23.3, complying with the specification of this paint. Finally, the brushability and the accelerated wear by scrubbing, in both cases, good results were achieved, which demonstrated the reproducibility of the formula in the production plant.

In the case of exterior matte paint, the critical variables that were evaluated were viscosity, coverage, degree of dispersion, scrubbing of the paint film and cracking at high thickness. The viscosity showed an average value of 91 KU, without adjustment in the quality control stage, being within the parameter since the allowed range is 87-97 KU; the hiding power of the paint did not require adjustment, standing at 98.15%, likewise, the degree of dispersion achieved during manufacture, remained within the desired particle size for this paint with a value of 45 microns.

On the other hand, the cracking at high thickness, in the evaluations carried out, was classified as very good in the estimation scale of the present test, since the formation of cracks in the paint surface was not observed.

Table 11. Physicochemical properties of the exterior white matte paint by slurry and pigment concentrate, after 7 days in stability at room temperature and accelerated stability in the furnace

Parameters	Matte exterior paint by slurry and CP (Room T.)	Matte exterior paint by slurry and CP (Furnace)
Viscosity (KU)	88	92
pH	8.99	8.65
Non-Volatile Solids (% m /m)	54.33	54.66
Hiding power (%)	97.04	97.73
% Whiteness	88.91	87.58
Yellowness	1.12	1.21
Degree of Dispersion (Micron)	45	45
Scrubbing (Cycles)	230	223
Brightness (°)	N/A	N/A
Gallon Weight (kg / gal)	5.35	5.43

KU: Krebs-Stormer; (%): percentage; (% m/m): mass /mass percentage, T.: temperature; CP: pigment concentrate

Finally, as for brushability and accelerated scrubbing wear, both provided satisfactory results, thus proving a good synergy of the resin emulsion with the other components of the paint.

3.5. Productions times of white products, the standard manufacturing process and the process by slurry and pigment concentrate of the premium line in the production plant

The record of the manufacturing times of the premium line is observed in Table 13, it is noteworthy that the time of the dispersion stage of the process by slurry and pigment concentrate, is equal to zero, because the pigments, filers and extenders were already dispersed, this being the most important stage in the development of the paint.

Table 12. Physicochemical properties of the white color of satin and matte exterior paints, by slurry and pigment concentrate obtained in the production plant

Properties	Satin paint by slurry and CP	Exterior matte paint by slurry
Viscosity (KU)	93	91
pH	8.9	9.2
Non-Volatile Solids (% m/m)	49.35	54.23
Hiding power (%)	96.99	98.15
% Whiteness	88.20	88.43
Yellowness	0.75	0.70
Degree of Dispersion (Micron)	20	45
Scrubbing (Cycles)	433	233
Brightness (º)	23.3	N/A
Gallon Weight (kg / gal)	4.94	5.40

KU: Krebs-Stormer; (%): percentage; (% m / m): mass / mass percentage, CP: pigment concentrate

It was evidenced an increase of time in the termination stage of the process by slurry and pigment concentrate, being 125 minutes, this caused by the pumping of the slurry and pigment concentrate, from their respective storage tanks to the termination tank and adjustment in the production plant.

In the total time of the paint manufacturing process of the paint via slurry and pigment concentrate, a saving of 102 minutes of work was evidenced, which is equivalent to 1.7 hours, boosting an increase in productivity with a low investment in equipment.

Contreras obtained similar results in his study, which achieved a 9.3% reduction in the dispersion stage, improving production time and increasing the number of dispersed batches per man-hour [33], [34], [35].

These results allow the generating a methodology based on the process, showing the real possibility of implementing the technique by slurry and pigment concentrate.

In the Tables 14, 15 and 16 show the stages with their manufacturing times.These results showed that it is possible to migrate to the implementation of the paint manufacturing process by slurry and pigment concentrate for the two paints of the premium line, reducing the manufacturing times for white products, thus increasing the production capacity of the plant in 20 working days.

Table 13. Averages manufacturing times for white products from the traditional manufacturing process and the slurry process and pigment concentrate from the premium line in the production plant

Stages	Tradicional process	Process by slurry and pigment concentrate
Dispersion (min)	140	0
Termination (min)	84	**125**
Setting (min)	55	53
Quality Control (min)	150	149
Total Time (min)	429	327

min: Minutes

Therefore, any provision made to increase productivity and decrease the execution time of operations is relevant to senior management, and its implementation must be analyzed with the long-term financial sustainability of the strategy in mind.

Table 14. Premium paint manufacturing process traditional way 5,000 gallon batches

Stages		Team
Dispersion (min)	140	TQ#1
Termination (min)	84	TQ#2
Setting (minutes)	55	TQ#2
Quality control (min)	150	TQ#2
Total process time (min)	429	-
Total process time (hours)	7.15	-
Effective working hours	8.00	-
Lots to be manufactured in 20 business days	22.38	-
Gallons to be manufactured in 20 business days	111,888	-

TQ # 1 (2,000 gallon capacity dispersion tank),
TQ # 2 (5,000 gallon capacity completion tank), min (Minutes)

Table 15. Paint manufacturing process by slurry and pigment concentrate (TiO_2) 2,000 gallon batch

Stages		Team
Dispersion (min)	140	TQ#1
Setting (min)	30	TQ#1
Quality control (min)	60	TQ#1
Pumping to storage tank (min)	45	-
Total process time (min)	275	-
Total process time (hours)	4.58	-
Effective working hours	8.00	-
Lots to be manufactured in 20 business days	34.91	-
Volume to manufacture in 20 business days	69,818	-

TQ # 1 (2,000 gallon capacity dispersion tank),
TQ # 2 (5,000 gallon capacity completion tank), min (Minutes)

Table 16. Premium paint manufacturing process by slurry and titanium dioxide concentrate 5,000 gallon batch

Stages		Team
Dispersion (min)	0	-
Termination (min)	125	TQ#2
Setting (min)	53	TQ#2
Quality control (min)	149	TQ#2
Total process time (min)	327	-
Total process time (hours)	5.45	-
Effective working hours	8.00	-
Lots to be manufactured in 20 business days	29.36	-
Gallons to be manufactured in 20 business days	146,789	-

TQ # 1 (2,000 gallon capacity dispersion tank),
TQ # 2 (5,000 gallon capacity completion tank), min (minutes)

Table 17. Estimation of the monthly productivity increase

Traditional way (Gal)	111,888
Way slurrys + TiO_2 concentrate (gal) *	146,789.0
Increment (gal)	34,900.9
Increase (%)	31.20

(*): Considering that slurry plus TiO2 more concentrated represents between 30-40% by volume of premium paints, a minimum monthly production by slurry and TiO2 concentrates of 58,716 gallons is required, estimated production (Table 14) in 69,818 gallons using TQ # 1.

4. Conclusions

Through the implementation of the slurry and pigment concentrate process, paints were elaborated that preserved the same physicochemical, mechanical, performance and quality properties in their final finish if compared with those elaborated by the traditional method, which allows to promote the development of the paint industries. The use of slurrys and pigment concentrates is an alternative for paint manufacturers because they can increase productivity at very low investment costs in equipment, also, the weighing time is reduced, dust free decreasing environmental pollution and lower losses of raw materials due to improper use of pigment containers, loads and extenders.

It was possible to reduce the manufacturing times of each paint with a saving of 102 minutes. The new process for the elaboration of the paints not only allowed the reduction of times, but also reduced the necessary steps to form the final product, if compared with the traditional manufacturing process, since the time of the dispersion stage is eliminated, which is approximately 2h and 45min (separating raw materials, weighing, beginning of dispersion, checking, pumping to the finishing tank and storage), depending on the loads and extenders, as well as, the machining and recycling processes of leftovers. Therefore, there is a reduction in operating costs (final product), storage and recycling (dispersion stage), making the method a viable option for its implementation in the coating industry.

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