Effect of Chitosan and Cationic Polyacrylamide on Optical and Mechanical Properties of Paper Made from Chemi-Mechanical Pulps

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The influences of nano-chitosan and cationic polyacrylamide (cPAM) on the optical and mechanical properties of paper made from chemi-mechanical pulp (CMP) were investigated. Bleached chemi-mechanical pulp (CMP) was selected as the control sample. The cPAM was considered at four levels (0%, 0.25%, 0.5%, and 0.75%), while chitosan was added to the CMP suspension at three levels (0%, 1%, and 2%). Paper test specimens were prepared according to TAPPI standards with a basis weight of 60 g/m^2, and their optical and mechanical properties were measured. The results indicated that the opacity, greenness, tear strength, burst strength, and Gurley seconds were increased, whereas brightness, water absorption, and *a** factor were decreased by increasing the amount of cPAM. Adding chitosan to CMP increased the *a** factor, tear strength, breaking length, burst strength, Gurley seconds, water absorption, and greenness in the resulting paper. When polyacrylamide and nano-chitosan were added simultaneously to CMP, the brightness, water absorption, and greenness of the resulting paper decreased, but opacity, burst strength, tear strength, and air resistance had an appropriate increase. In all treatments, the best results were found at 1% chitosan and 0.5% cPAM due to favorable optical and mechanical properties.

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INTRODUCTION

As a result of population growth, increased consumption of paper and paperboard, and restrictions on the use of raw materials, producing pulp from high-yield pulps and mechanical pulps have found their own special status and proponents. Such pulps are highly efficient (over 85% yield), and the amount of the dissolved wood material that is lost in processing them is less than for chemical and semi-chemical pulps. However, owing to the presence of lignin, extracted materials, and metal ions in these pulps, their use is confined to short periods of time. Additionally, they undergo photo-yellowing in the long run (Vaysi and Kord 2013). Chemi-mechanical pulp (CMP) is normally produced via several types of treatment. These types of pulps have a yield between 80% to 90%.

In comparison to the CTMP method, the CMP process requires more pre-treatment time and temperature. In this method, wood chips are treated in one or two phases at a lower temperature of 100 °C. Then chemical treatment with sodium sulfite (Na_2SO_3) is performed at a temperature above 100 °C (Rezazadeh *et al*. 2022). After pulp cooking, the refining operation is used at atmospheric pressure in one or two steps (for less or more freeness, respectively). Due to the use of more chemicals in the CMP method, the quality of the resulting pulp is better than CTMP pulp. The final freeness level of CMP is approximately between 300 and 400 mL. The CMP of Mazandaran Wood & Paper Industries is produced from hornbeam (75%), poplar (20%), and beech (about 5%) trees. In the future, poplar and imported woods will gradually replace beech (Barzan and Soraki 2002; Rashidi Joybari *et al*. 2015).

In addition, in making high-quality and durable paper, mechanical and chemi-mechanical (CMP) pulps are less desirable than chemical pulps. This is due to more degradation in the fibers, lower average fiber length, more fiber fines, less retention of fines and fillers, more residual lignin, and lower mechanical properties. On the other hand, these pulps are usually used for the production of newsprint, printing and writing papers, and cardboard due to their higher efficiency and better printability properties.

Accordingly, Mazandaran Wood & Paper Industries (located in the city of Sari, the Provincial capital of Mazandaran) annually manufactures around 52,000 tons of paper for newspapers and 38,000 tons of print and stationery papers (per order) through the chemi-mechanical pulping process of hornbeam, beech, and poplar. For this purpose and to improve of runnability of paper during production and printing, there is a need to use 15% of imported long fibers in combination with CMP made in Iran. The imported pulp, which is usually softwood kraft pulp, not only brings about dependency on the producing countries, but also causes a large amount of financial loss annually (Barzan and Soraki 2002). In addition, for enhancing optical amplification and printability of the final paper features while reducing the final costs by 5 to 15%, non-fibrous additives (fillers) are added to the paper pulp in the blend chest.

Many components and additives to a papermaking process have a negative electric charge (*i.e.*, they are anionic) and therefore they are not well fixed on the pulp fibers. In addition, they can easily fail to be retained in the wet-web, which is forming on the paper machine wire. To retain the fines on the pulp fibers, additives with positive charges are added so that the fillers and the fines are not disposed through the paper forming machine wire (Vaysi and Ebadi 2021). Using cationic additives such as poly-DADMAC, chitosan, and polyacrylamide (which possess positive electrical charge) in stock and the role they can play in improving retention and optical properties and strength of the paper that was made from CMP have encouraged researchers to study them.

A cationic copolymer of polyacrylamide was used in this connection. This polyelectrolyte is based on acrylic polymers and has high molecular weight and net positive ionic charge. Such polyelectrolytes have the form of a glasslike solid when dry at room temperatures; they may be produced in the form of white powder, transparent grains, and flaky shapes (Tajik 2015). Polyacrylamide products have wide uses in the paper industry as substances that facilitate hydration. As an isolated polymer system, a traditional function of a cationic polyacrylamide copolymer is to act as a retention aid *via* a bridging mechanism. Through comparison between simple polyacrylamide and a bentonite–polyacrylamide combination in virgin paper pulping, it was revealed that approximately half the amount of polymer was required to reach a certain rate of water release during paper formation (Wågberg *et al*. 2002).

Chitin is the next most abundant biopolymer in nature after cellulose, hemicellulose, and lignin. Structurally, it resembles cellulose, only differing in that chitin has an acetamide groups ($NHCOCH_3$) at the C_2 position. The de-acetylated derivative of chitin is known as chitosan. Chitosan is a biodegradable, biocompatible, antibacterial, and antiviral material taken from renewable resources such as sea crustaceans. The similarity between cellulose and chitosan leads to its compatibility with the cellulose present in paper fibers (Fig. 1) (Steckel and Nogly 2003). According to the carbon position in the cellulose structure and by removing an OH group in the glucopyranose ring of cellulose and an amine H in the C_2 carbon position of chitosan, a covalent amine bond is formed and a water molecule is released from the reaction medium. On the other hand, the positive charge associated with the amine group is able to form an ionic bond with the negative charges of cellulose fibers as well as other negative charges in the stock (Fig. 2) (Pourkarimi Dodangeh *et al.* 2016).

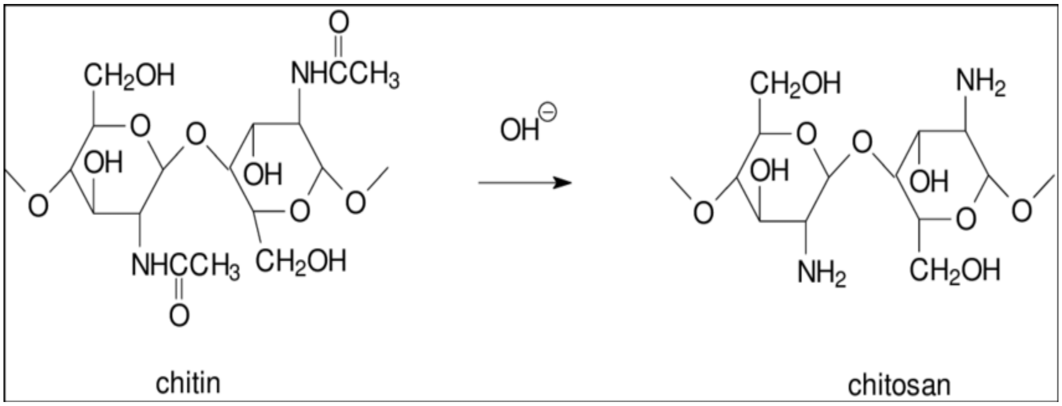

Fig. 1. Formation of chitosan from chitin (Rahmaninia *et al*. 2015)

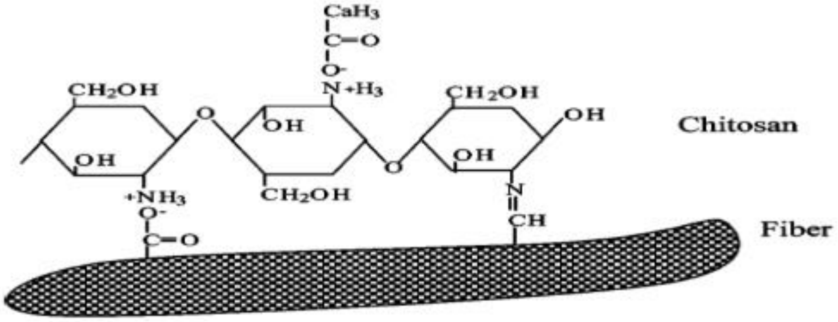

Fig. 2. How chitosan reacts with fibers (Pourkarimi Dodangeh *et al.* 2016)

Chitosan forms stronger inter-fiber bonds and makes stronger paper due to interactions between positive and negative electrical charges in cellulose materials (Pariser *et al*. 1998; Vanerek *et al*. 2006; Rasoulpour *et al*. 2012). Ramaninia *et al*. (2014) reported that treatment of CMP with 1.25% of chitosan at a fixed level of 0.3% of nano-bentonite in alkaline pH showed the highest strength. Davoodian *et al*. (2018) investigated the effects of utilizing dual system of cationic starch nano-silica and nano-cellulose polyacrylamide on the physical and strength properties of the handsheets from cotton chemical pulp. Adding nano-cellulose and polyacrylamide to cotton pulp had no impact on the pulp strength; nonetheless, using cationic starch together with nano-silica increased the density of the produced paper. Mohseni Tavakkoli *et al*. (2014) reported that tensile index with triple layer deposition was increased by 16%, and the paper's uniformity was slowly decreased. Tajik (2015) applied nano-cellulose, polyacrylamide, and cationic starch for strengthening internal hydrogen bonds of print and stationery papers made from bagasse and reported that the best strength in paper was obtained with 3% of nano-cellulose and 6% of cationic starch.

Rashdi Joyibari *et al*. (2015) examined the effect of cationizing the fibers of conifers by EPTMAC and its mixing with CMP. The results showed that mixing the long cationic fibers with CMP boosts the mechanical properties and retention of the fines. By studying the effects of functions in nano-cellulose biopolymer and chitosan system on the properties of pulp and recycled paper, Pourkarimi Dodangeh *et al*. (2016) concluded that not only did chitosan not boost the strength, but it decreased it. However, its performance has been better than nano-cellulose.

Modifying the surfaces of kraft pulp in the presence of chitosan polymer, Rasulpur *et al*. (2012) reported that even without peroxide treatment, chitosan can act as a dry strength-improving substance, and this outcome can be attributed to chitosan's capability in creating three types of bonds, namely hydrogen, ionic, and covalent. On the other hand, surface modification of fibers by means of hydrogen peroxide raises the extent of negative electrical charges on the fiber surfaces. Such fibers, together with chitosan, it will form a successfully working dual system (which possesses a net positive charge).

By examining the effect of adding poly-aluminum chloride (PAC) and nano-chitosan to CMP, Rezazadeh *et al*. (2021) reported that by separately adding 1% PAC and 2% chitosan and later simultaneous addition of 2% chitosan and 1.5% PAC to the CMP, they improved most properties in the produced paper.

Nano-chitosan and polyacrylamide have been used separately and simultaneously to improve CMP properties. The mechanism of the simultaneous behavior of polyacrylamide and chitosan in improving the properties of pulp, especially paper obtained from the CMP has not been investigated. Hence, the main purpose of this research is to investigate and report the most appropriate results.

EXPERIMENTAL

Materials

CMP pulp

Bleached and refined CMP with freeness level of 300 SCF (mL) was procured from paper machine unit (namely Unit 600) of Mazandaran Wood & Paper Industries (Sari, Iran), and some pulp was separated as the control sample. It should be noted that in Iran, CMP-type pulp is used in Mazandaran Wood & Paper Industries from common hornbeam trees (75%) and poplars and beeches (25%).

Polyacrylamide

A cationic copolymer of acrylamide (cPAM) distributed by the Degussa company with the trade name Farinret K325 was used in this work. It is not consumed in Mazandaran Wood & Paper Industries. The alum ($Al_2(SO_4)_3$) is the only auxiliary additive (for retention) consumed for newspaper paper manufactured in Mazandaran Wood & Paper Industries. The cPAM has a high molecular weight with moderate cationic electric charge. For the purpose of this research, cationic polyacrylamide was prepared as a solution with a concentration of 0.1%. It was used with 0.25%, 0.5%, and 0.75% ratios (solids basis) in the stock (Tajik 2015).

Chitosan preparation

Chitosan (“Seafresh”, Thailand) was prepared from the crustaceans’ exoskeletons. The material was described as nano-chitosan, and its powder had an average diameter of 40 to 60 nm. The product was obtained with a deacetylation degree of 93% and a molecular weight of 270 kDa. For preparation, the required amount of chitosan was dissolved in a 1% acetic acid, and then the mixture was stirred at room temperature for 2 h. Chitosan was loaded at 1and 2% of the dry pulp weight (Table 1), (Rezazadeh *et al.* 2022; Ashoori *et al.* 2005; Nicu *et al.* 2010).

Table 1. Experimental Conditions

Chitosan	cPAM	Number of Handsheets	N
0	0	10	3
0	0.25	10	3
0	0.5	10	3
0	0.75	10	3
1	0	10	3
1	0.25	10	3
1	0.5	10	3
1	0.75	10	3
2	0	10	3
2	0.25	10	3
2	0.5	10	3
2	0.75	10	3

N; number of repetition in each of properties

Methods

Optical and strength properties

To measure the optical and mechanical properties of paper made from the above-mentioned pulp and from bleached CMP of Mazandaran Wood and Paper Industries (as the control sample), first, according to the Test No. T205om-88 of TAPPI standard, some handsheets were prepared with 60 g/m^2 basis weight. A spectrophotometer was employed to measure the optical properties of the produced paper (Table 1). The device employed was capable of identification of the color of paper products through the CIElab system. The performance of this device is based on the light reflection property received from the surface of the material that is being investigated. The degree of brightness and opacity of the papers were determined *via* standard tests of T452om-01 and T452om-02. Then, mechanical properties of the produced papers, especially tear, burst, tensile strengths, and air resistance were measured and compared by means of the T414om-98, T403om-02, T494om-96, and T460om-02 TAPPI standards, respectively. Lastly, water absorption (Cobb 60) of the handsheets was measured using the T441om-04 test (TAPPI 2009; Fahmy and Mobarak 2009).

Statistical Data Analysis

Data analysis was done by using SPSS. Factorial design and multi-way ANOVA were employed to explore the independent and the interactive effects of variables. Also, the Duncan method was used to compare the significance of apparent differences between mean values for different experimental conditions (Table 2).

Table 2. Multivariate Analysis of Variance between CMP Properties during the /use of cPAM and Chitosan

Properties	Corrected Model (Variables)	Type III Sum of Squares	df	Mean Squares	f	sig
Brightness	Chit (A)	2.921	2	1.460	8.97	0.001*
	cPAM (B)	250.832	3	83.611	513.65	0.0001*
	A×B	29.251	6	4.875	29.949	0.0001*
Opacity	Chit (A)	38.922	2	19.451	97.99	0.0001*
	cPAM (B)	253.483	3	84.494	425.426	0.0001*
	A×B	61.356	6	10.226	51.488	0.0001*
Tear	Chit (A)	325.500	2	162.750	1.365	0.275^{ns}
	cPAM (B)	634.000	3	211.333	1.772	0.179^{ns}
	A×B	838.500	6	139.750	1.172	0.354^{ns}
Breaking Length	Chit (A)	0.100	2	0.050	2.648	0.091^{ns}
	cPAM (B)	3.923	3	1.308	69.414	0.0001*
	A×B	2.549	6	0.425	22.550	0.0000*
Air Resistance	Chit (A)	25.741	2	12.870	22.892	0.0001*
	cPAM (B)	5.743	3	1.914	3.405	0.034*
	A×B	2.888	6	0.481	0.856	0.540^{ns}

Note: Chit stands for chitosan, cPAM stands for Polyacrylamide, * Significant at 0.05 and ns: Non-significant

RESULTS AND DISCUSSION

Statistical Data Analysis

Multi-way analysis of independent and interactive factors was conducted on the optical and mechanical properties of the paper made from CMP, with cPAM and chitosan used in the production procedure. The results showed that chitosan significantly affected all paper properties except tear strength. The independent effects of cPAM on all the properties of the produced paper were statistically significant, except for tear strength. Interactive effects of chitosan and cPAM were significant relative to the properties except for tear strength and air resistance at the 1% level (Table 2).

Brightness

Increasing amounts of cPAM led to less brightness in the paper made from the CMP process compared to the control sample. By contrast, adding chitosan resulted in more brightness in the paper made from CMP. Simultaneously, adding cPAM and chitosan reduced the brightness made from CMP in comparison to the control sample. Among various treatments, the highest level of brightness was observed in CMP by adding 1% and 2% of chitosan to the control sample. Accordingly, the paper had an adequate brightness by adding 0.25% cPAM in comparison to the control sample. In other words, there are many chromophores of lignin or extractives in these pulps that have been oxidized and bleached with hydrogen peroxide. By increasing the polyacrylamide and nano-chitosan through the cationic charge, the clumping in the suspension and the retention of fines increases, and as a result, the light absorption coefficient increased and the brightness decreased (Tajik 2015; Vaysi and Ebadi 2021).

Statistical data analysis showed a significant difference among the brightness in different treatments at 1% level (Fig. 3).

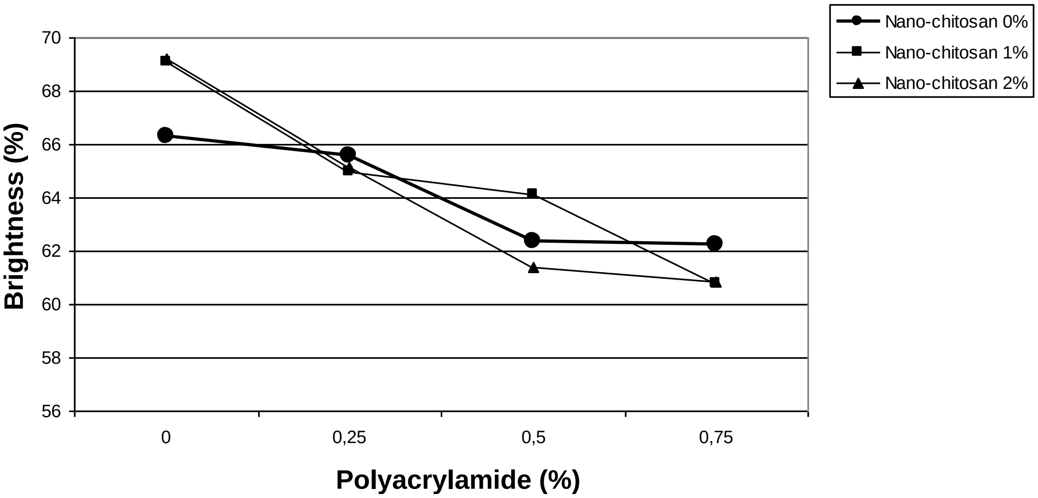

Fig. 3. Comparing brightness in the paper made by adding polyacrylamide & Nano-chitosan to CMP

Opacity

The results were indicative of an increase in opacity as a result of increasing cPAM in the paper made from CMP. The opacity of CMP was not tangibly changed when 1% and 2% nano-chitosan was added to the mixture. Adding polyacrylamide and nano-chitosan to the CMP at the same time raised the level of opacity in the paper compared to that of the control sample. The highest opacity was observed in the paper (in comparison to the control sample) when 0.25%, 0.5% of polyacrylamide and 2% of nano-chitosan were simultaneously added to the compound. The paper made through simultaneously adding 1% and 2% nano-chitosan and polyacrylamide to the CMP of the pulp mill brought about a proper opacity in comparison to the control sample.

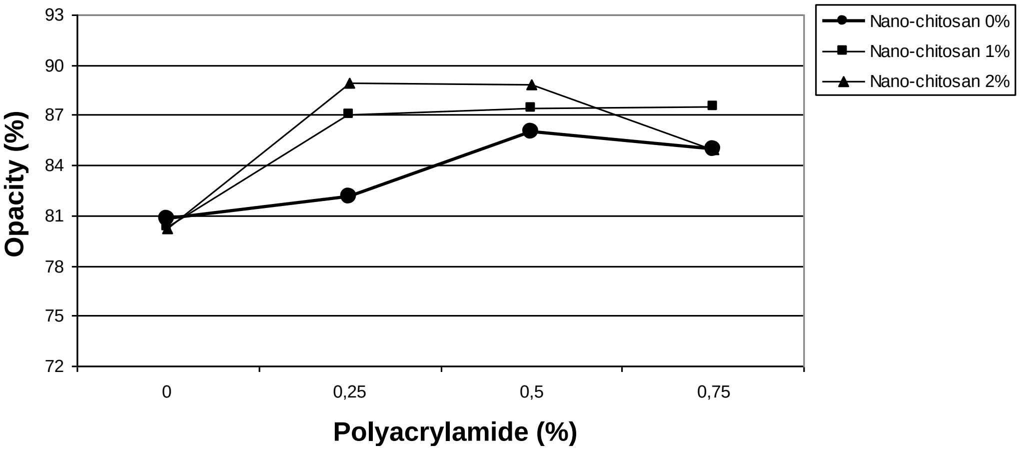

Fig. 4. Comparing opacity in the paper made by adding polyacrylamide & nano-chitosan to CMP

On the other hand, in addition to increasing dry resistance, chitosan can also reduce the light transmission in paper and increase its opacity by increasing the retention of fines/fillers and paper density (Vaysi and Ebadi 2021; Rezazadeh *et al.* 2022). The statistical analysis illustrated that there was a significance difference between averages of opacity in various treatments at 1% level (Fig. 4).

*a** Factor

In the international color system (CIE *L*a*b**), the *a** factor represents the color spectrum red (positive) to green (negative) in the paper. Its value is highly important for newspaper, print, and stationery papers. Figure 5 shows that adding cPAM to the pulp compound decreased the *a** factor and boosted paper greenness. Such a boost in greenness in CMPs is regarded as favorable, in that pulps have high yield and lignin content. Through adding 1% and 2% nano-chitosan, the *a** factor increased, and there was a decrease in the greenness of the produced paper.

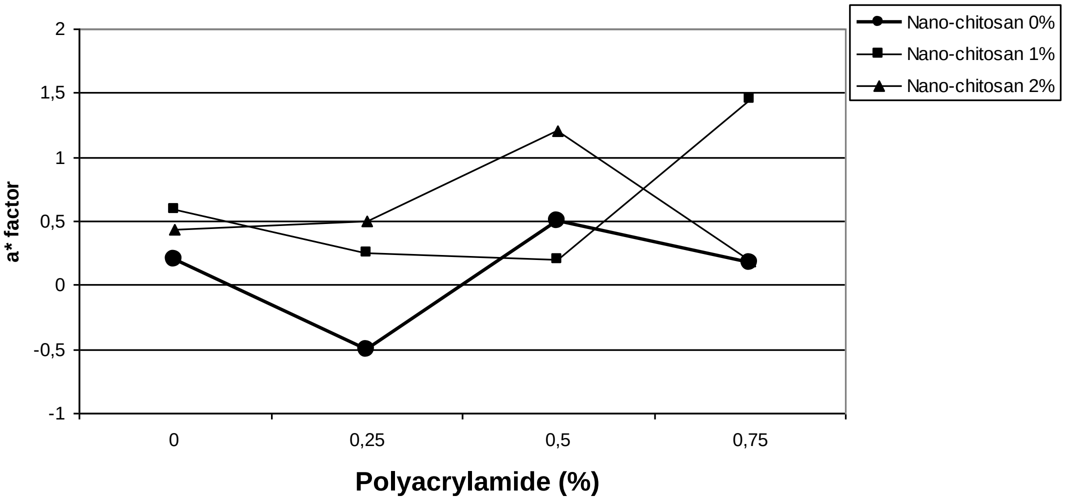

Fig. 5. Comparing *a** factor in the paper made by adding polyacrylamide & nano-chitosan to CMP

With simultaneous addition of cPAM and chitosan to the compound, the *a** factor in the paper made from CMP increased compared to that of the control sample and the greenness decreased. Among various treatments, the highest cases of greenness and lowest degrees of *a** factor in the produced paper were obtained when 0.25% of cPAM was added. Therefore, only the paper obtained from the simultaneous treatment of 1% nano-chitosan and 0.5% polyacrylamide, as well as the treatment of 0.25% polyacrylamide to CMP pulp mill had a more suitable *a** factor and greenness than the control samples. The analyses showed a significant difference in the statistical means of *a** factor in all treatments at the 1% level.

Tear Strength

As shown in Fig. 6, an increase in the amount of polyacrylamide led to an increase in the tear strength of the handsheets. By adding chitosan, the tear strength in paper obtained from CMP pulp showed an increase. The simultaneous addition of cPAM and chitosan to CMP significantly increased the resistance against tearing compared to the control samples. The highest tear strength in the produced paper was observed when adding 0.5% cPAM, as well as simultaneous adding of 1% chitosan and 25% cPAM. In most treatments, adding cPAM and chitosan (either simultaneously or separately) led to more tear strength compared to the control sample. Therefore, adding polyacrylamide (with positive electrical charge) caused the surface of the fibers to become cationic. In the next stage, fines and fillers will be attracted through adding nano-chitosan with potentials of triple positive charge (cationic charge) (Pariser *et al.* 1989; Vanerek *et al.* 2006; Tajik 2015). The continuous use of positive dual polyelectrolytes will keep higher amounts of colloidal components and fine particles on the fibers and will result in more dry strength (Wågberg *et al*. 2002; Hadilam *et al*. 2013). Accordingly, cationic polymers such as chitosan (due to high density and connection with cellulose fibers) will increase the retention of fines and improvement of strength properties (Steckel and Nogly 2003; Ashoori *et al*. 2005). Statistical analyses demonstrated that there is no significant difference in tear strength between the treatments of pulps at 5%.

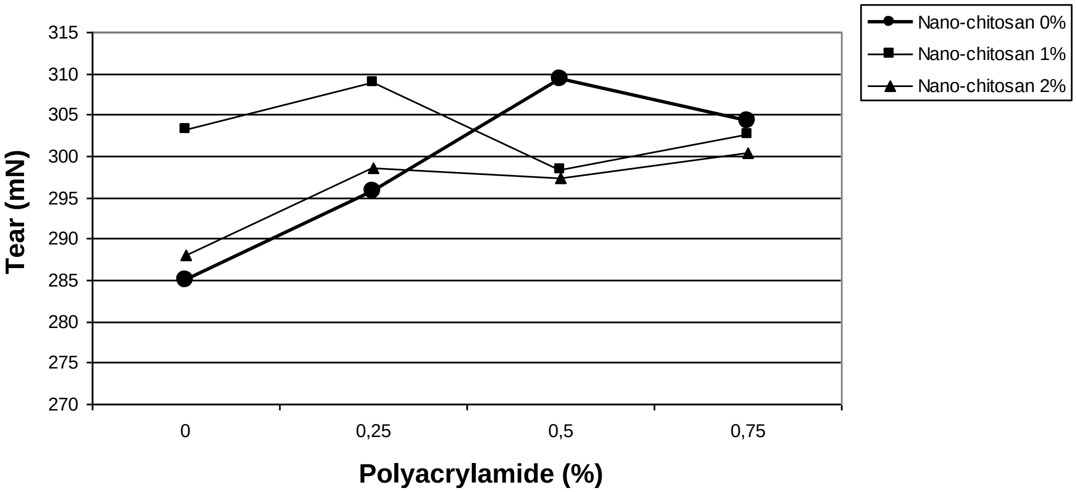

Fig. 6. Comparing tear strength in the paper made by adding polyacrylamide and nano-chitosan to CMP

Breaking Length

As shown in Fig. 7, adding 2% nano-chitosan to the CMP increased the breaking length. Because breaking length depends on the connections between cellulosic fibers, chitosan (with its structure similar to cellulose fibers) works as an additive for boosting dry strength (Vaysi and Kord 2013). Adding polyacrylamide to the compound first increased the breaking length and then slightly diminished it. With the addition of cPAM and chitosan simultaneously to the CMP (except for when polyacrylamide was at 0.5%), a suitable increase was observed in the breaking length. The highest breaking length resulted when 1% chitosan and 0.75% cPAM were added to the CMP. Therefore, adding the cPAM confers a positive charge to the fiber surface (cationic charge). After that, by adding chitosan with 3 times the positive charge density, it absorbs fines and fillers on the side of the fibers. Consecutive use of positive and binary polyelectrolytes results in greater colloidal components, retention of fine particles on fibers, and greater dry strength (Wågberg *et al.* 2002; Hadilam *et al.* 2013; Nasir and Daud 2014; Fosso-Kankeu *et al.* 2017). In this regard, chitosan has amine groups that may provide amide ionic, hydrogen, and covalent bonds, further developing the connections among fibers (Vanerek *et al.* 2006; Heermann *et al.* 2006). Statistical data analysis indicated that there was a significant difference between the statistical means of breaking length in various treatments at the 1% level.

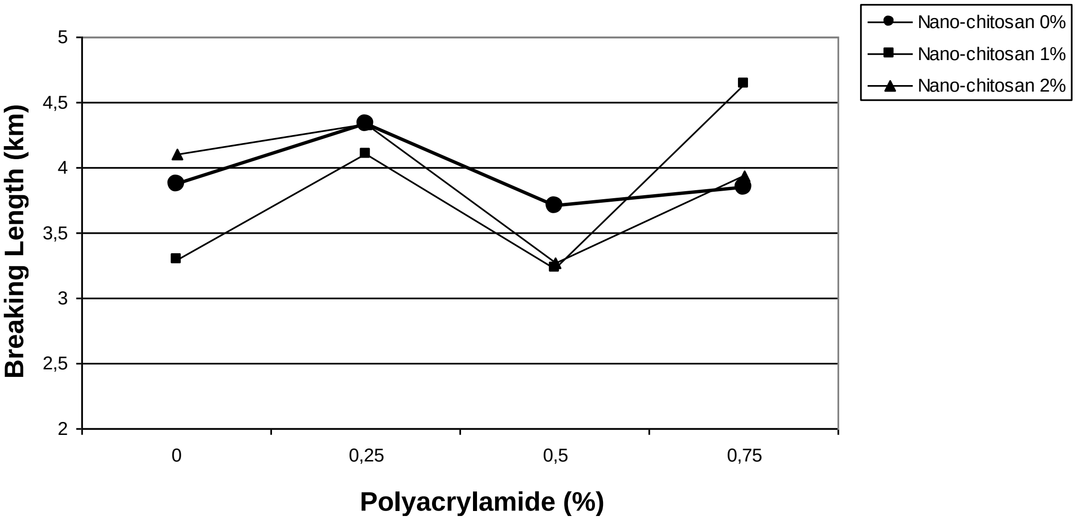

Fig. 7. Comparing breaking length in the paper made by adding polyacrylamide & nano-chitosan to CMP

Burst Strength

Figure 8 shows that increasing the polyacrylamide amount led to a slight increase in the burst strength in the paper made of CMP. Likewise, an increase of chitosan also increased the burst strength in CMP. Simultaneous adding of cPAM and chitosan to the CMP resulted in proper burst strength in the produced paper in comparison to the control sample.

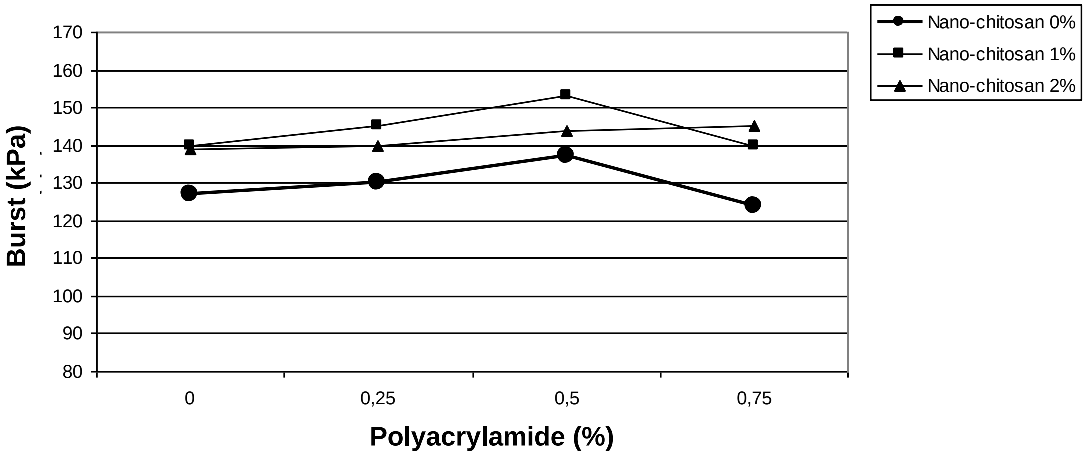

Fig. 8. Comparing burst resistance in the paper made by adding polyacrylamide & nano-chitosan to CMP

Out of a variety of treatments, the highest level of burst strength (compared to the control sample) was observed when 0.5% of cPAM and 1% chitosan were added to the pulp simultaneously. Accordingly, all testing treatments (except at 0.75% level of cPAM) achieved favorable burst strength compared to the control sample. Therefore, cationic polymers such as chitosan (owing to high positive electrical charge) can easily make connections with cellulose fibers. This property leads to greater retention of fines. Hence, one might claim that chitosan, in addition to its performance as a dry strength boosting substance, can ameliorate paper strength properties by contributing to the retention of the fines (Nicu *at al*. 2010). A more specific surface of the fibers along with more thinness and flexibility of fibers would ultimately result in increased bond and greater burst strength of paper owing to the establishment of more hydrogen bonds (Vaysi and Kord 2013). Since the structure of chitosan is similar to that of cellulose, it can have a favorable level of compatibility with the surface of cellulose fibers to create a wide variety of different bonds with it (Nada *et al*. 2005). Statistical data analysis made clear that there was a significant difference among the statistical means of burst strength in various treatments at 5%.

Air Resistance

Figure 9 shows that the air resistance increased by increasing cPAM in CMP. Furthermore, the addition of chitosan to CMP increased the air resistance as well. With simultaneous adding of cPAM and chitosan to the CMP, the paper showed increased air resistance in comparison to the control sample. From among different treatments, the highest air resistance in the paper made of CMP was observed when 0.5% of cPAM and 1% of chitosan were simultaneously added to the mixture, while the least air resistance was observed in the paper made of the pulp obtained from Mazandaran Wood and Paper Industries (*i.e.*, the control sample). Accordingly, homogeneous scattering of cellulose nano-fibers and extended network and level of fiber bindings causes reducing pores and interstices of the paper structure. Besides, due to the zigzag path of void spaces created in the paper, it takes air molecules longer to go through the paper. Therefore, a certain volume of air requires a longer time to pass through the paper as the permeability lessens within the paper and air resistance increases (Syverud and Stenius 2009). Data analysis revealed that there was a significant difference among the means of air resistance in various treatments at 5%, but there was no significant difference between air resistance and the interactive effect of nano-chitosan and polyacrylamide.

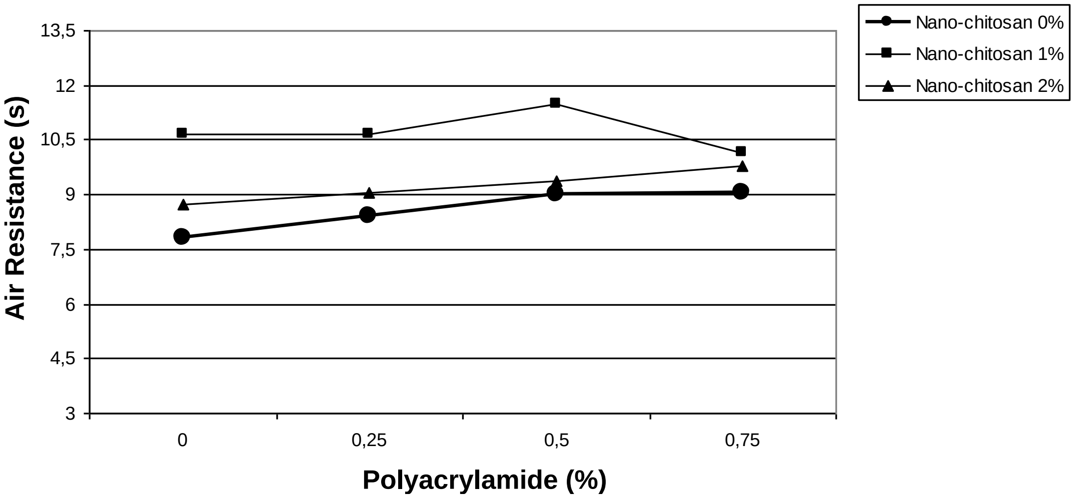

Fig. 9. Comparing air resistance in the paper made by adding polyacrylamide & nano-chitosan to CMP

Water Absorption (Cobb 60)

As shown in Fig. 10, the increase in cPAM and chitosan led to remarkable decrease of water absorption in the paper made of CMP. Simultaneous adding of cPAM and chitosan caused a drop in water absorption in the paper made of CMP, compared to that of the control sample. Among the various treatments, the highest water absorption belonged to the control sample CMP, while the lowest amount of water absorption was observed when 0.75% of cPAM and 2% of chitosan had been added to CMP. Accordingly, in all treatments, especially in the treatment made of pulp through simultaneously adding cPAM along with 1 and 2% of chitosan, less (more favorable) water absorption was observed in comparison to the control sample. Such a drop in water absorption validated the influence of chitosan and cPAM. Capability of establishing hydrogen bond among amine groups of chitosan and hydroxyl groups of fibers makes it possible to establish electrostatic bonds among anions at surface of fibers. In theory, carboxyl groups and amine cationic groups, might form covalent bond through the reaction between the chitosan groups and aldehyde groups of fibers including theoretical binding of chitosan to cellulose fiber surfaces and decrease certain water absorbing groups in the produced paper (Nikolaeva 2010). Statistical analyses demonstrated that there was a significant difference among the means of water absorption property in various treatments at 5% (Fig. 11).

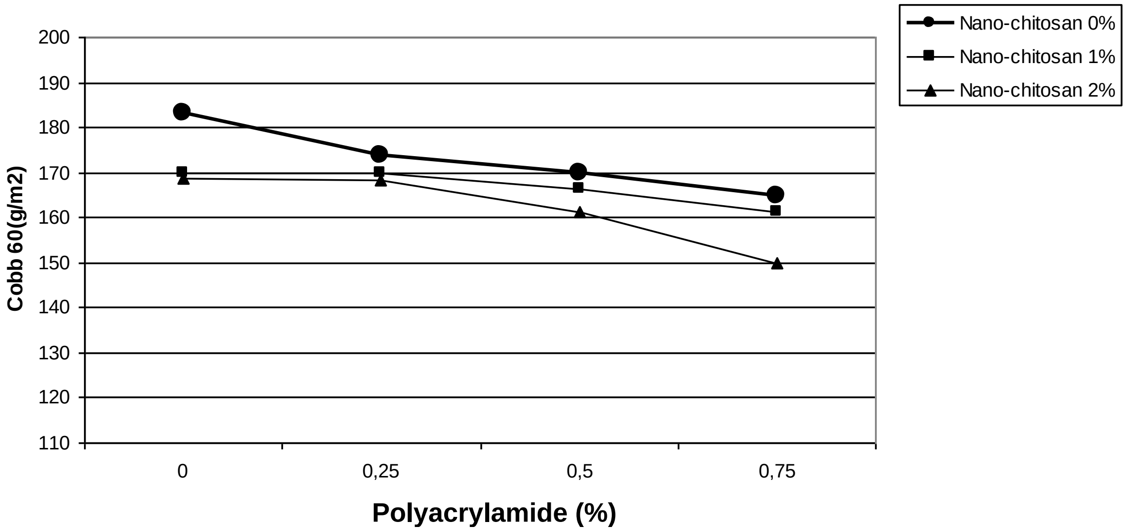

Fig. 10. Comparing water absorption (Cobb 60) in the paper made by adding polyacrylamide & nano-chitosan to CMP

CONCLUSIONS

The present study was conducted to investigate the potential effects of using cationic acrylamide copolymer (cPAM) and chitosan on the strength and optical properties of chemimechanical pulp (CMP) handsheets. The findings are presented in this section:

1. The addition of cPAM to CMP furnish led to an increase in the opacity, greenness, tear strength, burst strength, and air resistance of the handsheets, as well as decreased brightness, water absorption, and *a** factor (red coloration). The most favorable results in the hand-sheet were observed as a result of adding 0.5% cPAM to CMP.
2. Adding chitosan to CMP as well increased brightness, *a** factor, tear strength, breaking length, burst strength, and air resistance in the resulting paper, but it led to less water absorption and greenness in the paper. Therefore, the most appropriate paper properties were obtained by adding 1% and 2% chitosan to the CMP handsheets.
3. Adding cPAM and chitosan to CMP at the same time led to a decrease in brightness, water absorption, and greenness in the paper. However, it appropriately increased opacity and burst strength, tear strength, and air resistance. In all of the experimented treatment, the best of interaction treatments was found at 1% of chitosan and 0.5% of cPAM due to favorable properties in optical and mechanical properties.
4. The cPAM contributes to aggregation and flocculation operations by absorbing on the surface of colloidal particles and creating "particle-polymer-particle" bridges. This mechanism increases the rate of particle destabilization, and leads to rapid coagulation of particles as well as ultimately improving particle~~s~~ retention.

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