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Invention of novel continuous nitropulper technology for producing commercial nitrocellulose of wood pulp sheet

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Nitrocellulose is one of the most important cellulose derivatives used in industry and commerce, produced from raw materials such as cotton linters, dissolving wood pulp, or pure/mixed cellulose pulp. This study aims to develop an efficient process for converting pulp into nitrocellulose while minimizing particle and dust formation, acid waste, fiber damage, and production bottlenecks during nitration and boiling stages. The research involved opening dense wood pulp sheets (88–90% purity) using a laboratory mixer and a pilot-scale nitropulper. Simultaneous nitration was conducted in a mixed acid solution (27% nitric acid, 65% sulfuric acid, 8% water) with varying acid-to-cellulose ratios (65:1 to 15:1) for 1 to 5 min. Pre-nitration was carried out for 4 min, followed by post-nitration (16–36 min) to ensure complete reaction. The nitrocellulose was then deacidified, boiled in an autoclave (with water-to-nitro pulp ratios of 30:1 to 5:1), milled, and washed. Results showed that sheet opening was incomplete at 1–2 min, but after 3 min—even at the lowest acid ratio (15:1, 5% consistency)—full opening and nitration were achieved. The final nitrocellulose exhibited excellent quality: no unnitrated particles, low lacquer turbidity (11), high stability (Bergmann stability ≤ 1.4 mg), low alkalinity (0.01), minimal acetone insolubility (0.11%), and few physical impurities. Additionally, blending 90%-purity wood pulp with 99%-purity cotton linters improved lacquer quality. FT-IR and DSC analyses confirmed structural similarity between wood-pulp-derived nitrocellulose and cotton-based nitrocellulose, with comparable NO_2/OH peaks (FT-IR) and decomposition temperatures (~ 202 °C vs. 201 °C). GPC tests showed average molecular weights of 55,303 Da (wood pulp) and 59,402 Da (cotton). The optimized process reduced acid-to-cellulose ratios (from 65:1 to 15:1 in nitration; 30:1 to 15:1 in boiling), increasing pre-nitrator and autoclave capacity. Cost-effective, high-quality nitrocellulose was successfully produced using a 70:30 wood pulp-to-cotton linter blend.

Keywords Nitrocellulose, Cellulose nitration, Dissolving cellulose, Cellulose derivatives, Lacquer, Nitration

Environmental consciousness and the depletion of natural resources like fossil fuels, minerals, natural gas, etc. shifted attention towards renewable products. Among the naturally occurring structures, cellulose is one of the most versatile and abundant natural polymers, which can be obtained from different sources like plants, algae, bacteria, or tunicates[1–3]. Cellulose ($C_6H_{10}O_5$) is a linear polysaccharide consisting of a long chain of anhydroglucose units connected by β-1, 4 glycoside bonds. Nitrocellulose is a versatile material with a wide range of applications across various industries that derivate of cellulose polymer[4–9]. Nitrocellulose is one of the most energetic polymers that have extensive importance in many vital applications. Nitrocellulose has proven itself, since it was accidentally discovered, and until now as a pioneering material of great properties that can be used in different fields without faltering[1–3]. The applications are mainly related to its relatively high elasticity and mechanical strength. These properties result directly of cellulose structure, which consists of long chains of polysaccharide molecules[10–12]. Not only nitrocellulose, but all cellulose derivatives, such as other esters and

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cellulose ethers, have a specific property[13]. Nitrocellulose is used in the manufacture of smokeless gunpowder, blasting gelatin, dynamite, films, celluloid, clothing, artificial leather, woodworking, printing, adhesives, food and in the pharmaceutical industry[14,15]. There are different types of nitrocellulose, each with different physical properties and specific applications. For the production of nitrocellulose, cellulose fibers from cotton linters pulp, high-purity cellulose fibers and pulp in pure or mixed form are used[16–19]. Cotton Linters pulp is usually in the form of compressed, fluffy bales of 150–200 kg. After opening the wrapping and the packaging wire, it is feed directly into the production line and used in the production process. However, wood pulp is delivered to the world in the form of rolls or sheets and therefore cannot be used directly. There are two methods for converting sheets into fluff[20,21]:

Dry method

In this method, the sheets must be placed in a hammer mill, where the impact of their fibers opens them up and separates them into fluff. Hammer mills have a number of disadvantages, such as low efficiency (85–90%), high noise pollution, low safety, damage and beating of the fibers, high dust generation (about 10%), low capacity (2000 kg/day), very high fire risk and the need for an operator to feed the sheet to the mill[22,23].

Wet process

In this process, the sheets are opened in the pulper and feed into the storage tank. From there, they are transported through the head box over the Fourdrinier wire. The initial dewatering takes place in two stages through the vacuum suction system and the twin press rollers. It then enters the dryer where, after passing through the drying tunnel, it reaches a moisture content of 7% and is finally formed into a roll[24,25]. The resulting roll is opened by a fixed hammer mill. The disadvantages of this method include the high cost of processing sheet into roll and the sequence wetting and drying of the fibers, which causes the phenomenon of fiber horning, which reduces acid absorption in the fibers[24,25]. After fluffing the cellulose fibers, they are transported by a fan to the nitration department for nitration.

In the tradition process for producing nitrocellulose, nitration is carried out at a ratio of mixed acid to alpha cellulose of 65/1 in 4 min (pre nitration). For a further nitration, it is transferred to the second nitration station, where a further nitration is carried out over 36 min (post nitration).

Here the nitration is carried out with agitation and circulation. After nitration, the nitrocellulose is feed into a spent acid pusher centrifuge so that the excess acid is separated from the nitrocellulose and enters the spent acid tanks, and the resulting nitrocellulose is mixed with water and enters the immersion tanks. The nitrocellulose is then transferred to the boiling autoclave to remove the excess acid from the fibers and adjust the viscosity. Boiling takes place in two stages at a temperature of 120 °C with total duration of 4 h at a pressure of 2 bar. It is also rinsed 4 times with process water. After boiling and adjusting viscosity for controlling the softness of the fibers, they are placed in a conical miller for cutting and crushing the fiber and make the fibers fineness. Calcium carbonate is also added here to neutralize the nitrocellulose fibers and remove the remained excess acid. In the next step, the decanter is washed four times until the particles and physical impurities rise to the top of the decanter and are separated from there. Finally, it is dewatered by centrifuge and its moisture content reaches to 30%. Then isopropyl alcohol is added and alcoholic nitrocellulose is produced or plasticizer is added which, after lacquering with ethyl acetate, is converted into nitrocellulose granules and finally dried in a fixed bed dryer, reducing the moisture content to below 1%. Fairweather et al. (2019) presented a study entitled densified Nitrocellulose, in which they used densified cellulose for commercial and military Nitrocellulose and found that by doing so they were able to produce Nitrocellulose chips[26]. They concluded that in this way the cost of transportation of the raw materials could be reduced, as well as the cost of transporting the Nitrocellulose. Other advantages of this plan included high product quality, high production safety, increased yield, energy savings and reduced environmental hazards[27]. Mario pauquet and lan levac in 2023 investigated types of miller such as hammer mill, fixed hammer mill and cutter on nitrocellulose quality and finally on resulting propellant. They have been resulted that if exist agglomerated or unfluffy fibers pieces, they cannot fully nitrated and finally this agglomerated pieces remain in propellant matrix and has negative effect in properties of propellant especially ballistic performance burning rate, potential, mechanical properties and etc. also they have been showed that if milling and hitting of fiber was very much the yield of production will be decrease thus should be balance between agglomerated and fine fibers. Khalili Gashtroudkhani Ali and et al., studied about producing E grade nitrocellulose with chipping technology of wood pulp sheet. They resulted that with this technology they can produce high quality nitrocellulose and increasing capacity of nitrocellulose process in nitrator, autoclave and centrifuge and the resulted lacquer was good[27]. And in another research of them, they published a paper as A novel, low-cost, and high-efficiency method for nitrocellulose synthesis from plasma-modified cellulose. In this paper they used plasma for increasing reactivity and accessibility of hydrogen functional group and they decreased the consumption of acid, acid/cellulose ratio and increase the capacity of nitrocellulose producing[27]. As mentioned, this section, Hammer mills have a number of disadvantages, such as high noise pollution, low safety, high speed of blade rotation, high dust generation, high electricity consumption, low capacity, damaging (cutting) of fiber, fire hazard and need to an operator to feed the sheets into the miller. The aim of this study is develop a suitable process for converting pulp sheet into nitrocellulose with avoids of these disadvantages, and increases production capacity in the nitrating and boiling stages. Also, an attempt is made to open dense pulp sheets with a purity of about 89–90% on a laboratory and pilot scale using a laboratory mixer and nitropulper.

Experimental section

Materials

Alpha cellulose with a purity of 98.9% was obtained from Linter Pak Behshahr Company (as Table S1), sheet wood pulp imported from UPM company of Finland Also (as Table S2)., in order to accomplish the nitration

	Time (min)	1	2	3	4	5	Control sample
Specifications	Nitration	Incomplete	Incomplete	Complete	Complete	Complete	Complete
	Turbidity	17	12	9	8	8	8
	Stability	Unstable	Unstable	Stable	Stable	Stable	Stable
	Nitrogen (%)	10.80	10.80	11.40	11.56	11.63	11.65
	Insoluble in Acetone (%)	0.18	0.15	0.11	0.11	0.10	0.10

Table 1. Effect of nitration time on the properties of nitrocellulose fibers and the resulting lacquer.

First column	Sum of squares	D.F	Mean squares	F value	Sig.
Within group	48/031	5	8/008	2/003	0/131
Between group	56/000	13	4/002		
Total	104/031	19			

Table 2. Result of analysis of variance of turbidity of 3, 4- and 5-min period and control sample.

process on alpha-cellulose and wood pulp, the mixed acid was prepared from Karoon Petrochemical Company with compositions (as Table S3).

The specifications of the alpha cellulose cotton linters pulp used in this study were as follows (see in Table S1):

In this study, wood pulp sheets with specifications (see in Table S2) imported from UPM Finland were used.

For nitration of alpha cellulose fibers, E grade acid was used in the amount indicated in Table S3.

A laboratory mixer and hydropulper was used to open the sheet.

Specifications of mixer:

Volume: 2 L and speed: 1200 rpm.

Specifications of the hydropulper:

purchased of IDM Test company of Spain. Made of stainless steel 316 for pulping virgin or secondary (recycled) pulp. Capacities from 8 useful liters up to 15 L, to work from 30 to 1,400 g of paste. Working consistencies between 2 and 7%. Rotor speeds to 1200 revolutions per minute. Rotor shifted to create the Vortex effect.

Laboratory nitropulper: First, nitration was carried out with a 2-liter laboratory mixer, then with a 5-liter double-walled glass nitrator (for temperature control) at a temperature of 29 °C for a total of 40 min using a stirrer (Figure S1 and Figure S2).

After nitration, the excess acid is drained off by vacuum filter and the resulting nitrocellulose is washed with hot water. After washing and deacidification, the nitrocellulose is transferred to a boiling autoclave and boiled at 120 °C and 2 bar pressure in two 2-hour steps and then washed. In the next step, the resulting nitrocellulose is milled by laboratory PFI mill and neutralized with calcium carbonate (Figure S3). It is then washed in a decanter for 4–5 steps and finally dehydrated using a vacuum filter.

The obtained nitrocellulose (Figure S4) dissolved in isopropyl and ethyl acetate and convert to lacquer. The turbidity of the resulting lacquer is measured by refractometer. Nitrogen content calculated using the Kjeldahl and titration methods[28]. The Bergmann stability is determined using the Abel method. The insolubility in acetone and the alkalinity of the nitrocellulose are also determined using standard methods.

Nitrocellulose and lacquer were characterized using standard procedures, namely Nitrogen percent with ASTM D301 and ASTM D4795-94 (2003), Solubility with ASTM D365-1, Turbidity with ASTM D 7315-17, Fineness with ASTM D8394-21, and Bergmann with ASTM-DTL-244 C.

Results and discussion

The performance tests that can be evaluated in the final lacquer sample are turbidity, nitrogen content, stability and the presence or absence of physical impurities in the lacquer, which were compared with a lacquer sample obtained from fluffy cotton linters alpha cellulose. All analyses were performed and reported with at least threefold repeatability.

Investigation of the effect of mixing time on the quality of sheet opening and nitration in the nitropulper

In this study, the influence of opening time on the properties of nitrocellulose fibers and lacquer was investigated and compared with control sample of cotton linters alpha cellulose (see in Table 1).

As can be seen in Table 1, the nitration reaction in this stage is not fully completed in 1 and 2 min, which is clearly visible in the form of white (unreacted) pieces. These white pieces indicate that the sheet was not opened and the acid could not penetrate into the thickness, so it was not nitrated and the pulp sheet remains unnitrated. This cause increasing turbidity, unstable, and coarseness of lacquer. If the time is increased to 3, 4 and 5 min, because there is sufficient time for opening the sheet, the sheets are fully opened, the fibers assume a crushed state, which causes complete nitration (Table 2). It is also observed that turbidity of resulting lacquer was very high in 1 and 2 min due to the incomplete nitration and the presence of non-nitrated particles, while in 3, 4 and 5 min a uniform and transparent lacquer is obtained due to complete nitration. In addition, incompletely nitrated samples are unstable, while fully nitrated samples are stable. On the other hand, the percentage of nitrogen in

First column	Sum of squares	D.F	Mean squares	F value	Sig.
Within group	0/442	4	0/145	0/034	0/980
Between group	32/000	9	4/000		
Total	32/443	12			

Table 3. Result of analysis of variance effect of 3,4- and 5-minutes period in nitrogen content.

	Time (min)	1	2	3	4	5	Control sample
Acid/cellulose	$\frac{65}{1}$	Incomplete	Incomplete	Complete	Complete	Complete	Complete
	$\frac{55}{1}$	Incomplete	Incomplete	Complete	Complete	Complete	Complete
	$\frac{45}{1}$	Incomplete	Incomplete	Complete	Complete	Complete	Complete
	$\frac{35}{1}$	Incomplete	Incomplete	Complete	Complete	Complete	Incomplete
	$\frac{25}{1}$	Incomplete	Incomplete	Complete	Complete	Complete	Incomplete
	$\frac{15}{1}$	Incomplete	Incomplete	Complete	Complete	Complete	Incomplete

Table 4. Effect of using nitropulper in wood pulp nitration quality.

incompletely nitrated samples is low because they are not completely nitrated and vice versa (Table 3). The percentage of insoluble substances is also higher in samples with non-nitrated fibers and lower in fully nitrated samples (Figure S5). As mentioned, turbidity is very important for using lacquer in ink, packaging, coating ant etc. 1 and 2 min for opening and nitrating is not sufficient because turbidity of lacquer is high (12–17). But the turbidity of resulting lacquer with 3, 4 and 5 min nitrating is similar to control sample (about 8).

After opening, nitrating and boiling the samples, the milling process was also carried out on nitrocellulose (both fully and incompletely nitrated). The result, as can be seen, is that the finished nitrocellulose has the powder form as a result of the milling (Figure S6). However, this open powder is no proof of the high quality of the nitrocellulose. Since parts of it were not nitrated during the 1- and 2-minute periods, we have as a result a powder with a much lower nitrogen content, which does not dissolve in the solvent and remains in the lacquer in the form of non-nitrated particles or fibers (Figure S7).

Investigation of the effect of nitropulper speed on opening quality

In view of the fact that the nitropulper speed is 1200 rpm and cannot be changed, this speed was taken as the basis and constant speed for opening the sheets and nitrating.

Investigation of acid/cellulose ratio in the nitropulper on the nitration capacity

In this study, the effect of the ratio of acid to cellulose and its effect on simultaneous opening is investigated (see in Table 4).

As indicated in the sources, the suitable ratio of mixed acid to cellulose for nitration in the fluffy form of cellulose is usually 65/1. But this ratio can be reduced by using nitropulper. As can be seen, this ratio can be reduced to15/1 and nitration can be carried out. In the 1- and 2-minute periods, this is not desirable as non-nitrating pieces can be seen, and it is also not desirable at various ratios of acid to cellulose. Also, the ratio of acid to cellulose is at least 15/1 for 3, 4 and 5 min and 45/1 for cotton linters cellulose fibers due to the nature of fluffy, massy form and long length of fibers and the interlacing of the cellulose mass, which is bulky and cannot be used below 45/1 for cotton linters cellulose. From this, it can be concluded that the use of nitropulper technology can reduce the ratio of acid to cellulose from 65/1 to 15/1 in the best case. In other words, the nitration capacity in a 2 m^3 nitrator can be increased from 25 kg to 100 kg per batch, i.e. on the other hand the production capacity in the nitrator increases 75%.

Studying the effect of time on the reaction temperature of nitropulper

As far as the safety of nitration is concerned, this issue should also be investigated. In this study, the opening and nitration times in the pulper were set at 1, 2, 3, 4 and 5 min. As observed, the initial temperature of the mixed acid was 22 °C. It reached 26 °C in one minute, 28 °C in 2 min, 30 °C in 3 min, 33 °C in 4 min and 42 °C in 5 min. This shows that the nitration temperature rose sharply in 5 min, which is very unsafety for nitrating process. But for solving this problem, the cooling water jacket is suitable for opening and nitrating during this period. On an industrial scale, however, a jacket whose temperature can be reduced with coolling water can be used.

Investigating the effect of nitropulper on production efficiency in autoclaves

In this section, the effect of the opening time of the cellulose sheet in the nitropulper on the efficiency of nitrocellulose production in the autoclave was investigated (see in Table 5). As you can see, the ratio of water to nitro pulp in the sources and references is 30/1. By using the nitropulper technology, this ratio could be reduced from 30/1 to 10/1. The ratio 5/1 is also not suitable for pulp and cotton linters cellulose fibers at any time. This is because their consistency percentage is very much and washing, dewatering, viscosity adjustment and removal

	Time (min)	1	2	3	4	5	Control sample
Water/nitrocellulose ratio	$\frac{30}{1}$	Not OK	Not OK	OK	OK	OK	OK
	$\frac{25}{1}$	Not OK	Not OK	OK	OK	OK	OK
	$\frac{20}{1}$	Not OK	Not OK	OK	OK	OK	Not OK
	$\frac{15}{1}$	Not OK	Not OK	OK	OK	OK*	Not OK**
	$\frac{10}{1}$	Not OK	Not OK	OK	OK	OK*	Not OK**
	$\frac{5}{1}$	Not OK	Not OK	Not OK	Not OK*	Not OK*	Not OK**

Table 5. Effect of nitration time in nitropulper on nitrocellulose production efficiency in autoclave production. *Produce gel. **Difficult in rotating of agitator.

Parameter	Hammer mill	Fixed hammer mill	Hydropulper	Cotton linters nitrator	Nitropulper
Dust (waste)	High	High	No dust	Yes	No dust
Noise pollution	High	Low	No noise	No noise	No noise
Efficiency	Low	Medium	High	High	High
Safety	Low	Medium	High	High	High
Damage on fibers	High	Medium	Low	Low	Low
Capacity	Low	High	High	High	High
Mixing with alpha cellulose	No possible	Possible	Possible	No possible	Possible
Opening cost	High	High	High	Medium	Medium
Nitration quality	Medium	Medium	Low	High	High
Production cost. of nitrocellulose	2.1	2	2	3	1.4

Table 6. Comparison of different methods for opening cellulose Raw materials.

of acids from inside the nitro pulp fibers become more difficult. In 1 and 2 min, the resulting lacquer doesn't have the suitable quality due to the non-nitrated particles. But in 3, 4 and 5 min, when the nitration is complete, we can comment on the ratio of water to nitro pulp. The results show that the ratio can be reduced to 10/1, which increases the production efficiency in the autoclave. So, with the technology of using nitropulper, the production capacity of nitrocellulose in autoclave can be increased by three times. In other words: In an autoclave with capacity 20 cubic meter, the production capacity can be increased from 700 kg to 1900 kg per batch. Finally, production capacity increase about 63%.

Study of nitropulper effect on efficiency of centrifuge production

Since no cutting and beating processes take place in the fibers, the fibers are not crushed and fine, and no dust is formed. As a result, the fibers are uniform and long, and the passage of fine nitrocellulose fibers through centrifuge is not seen, and the efficiency at this stage will not change (100%).

Study of nitropulper effect on production cost of product

Table 6 shows the effect of methods used to prepare cellulose sheets for nitration, on production cost of nitrocellulose. As you can see, the price of wood pulp is half of the cotton linters alpha cellulose price. In addition, the quality of nitrocellulose lacquer is suitable for grade E and some grade A product. As can be seen from the table, the price of wood pulp raw material is 0.7 $, and on the other hand, no 36-minute post-nitrating time is required, and the consumption of mixing acid is also much lower and the autoclave capacity is increased, the production cost of nitrocellulose is $1.5, while the production cost of nitrocellulose with cotton linters alpha cellulose is $2.7. Finally, the production cost decrease about 44%.

FTIR result

As can be seen in Figs. 1 and 2, the FT-IR of nitrocellulose produced of wood pulp with a purity of 89% under the best conditions (time: 4 min, acid/cellulose:15/1) is similar to nitrocellulose produced of cotton linters with a purity of 98%. In this figure, the wave numbers 850 and 3500 refer to the hydroxyl group and 1250 and 1650 to the nitrous group. also, can see that intensity of nitrous group peak is very high and for hydroxyl group is very low. This shows that most of the hydroxyl group of the cellulose has been replaced by the nitrous group and nitrocellulose has been completely formed.

As can be seen in Fig. 3, the FT-IR of nitrocellulose produced from wood pulp with a purity of 89% after 2 min nitration differs from nitrocellulose produced of that after 4 min of nitration and cotton linters with a 98% purity. In this graph, the wave numbers 850 and 3500 refer to hydroxyl group and 1250 and 1650 to nitrous group. In addition, the intensity of peak of nitrous group is not very high and for hydroxyl group is higher, which

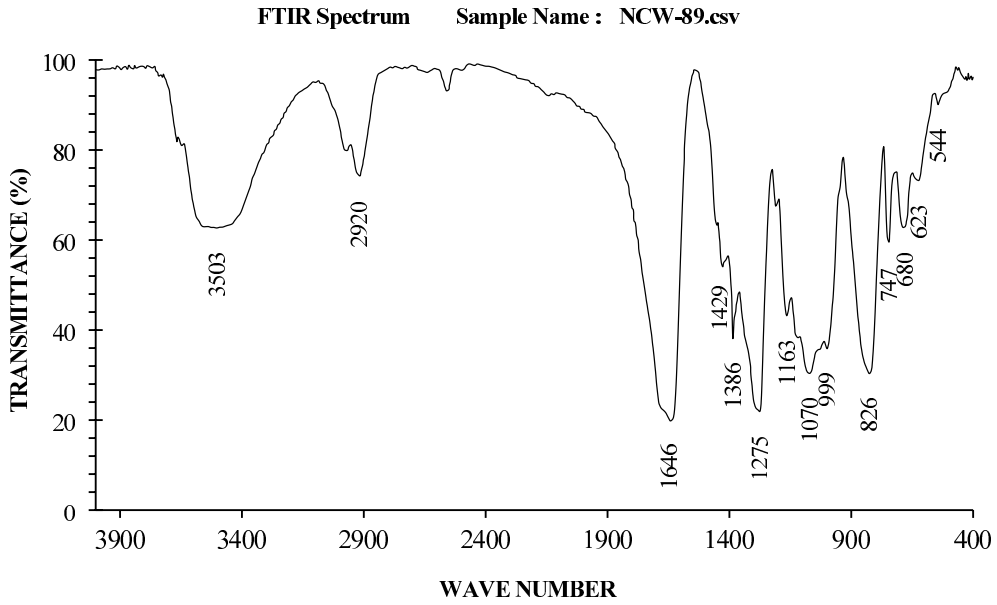


Fig. 1. FT-IR of nitrocellulose prepared of wood pulp with 89% purity from best condition (time: 4 min, acid/cellulose:15/1).

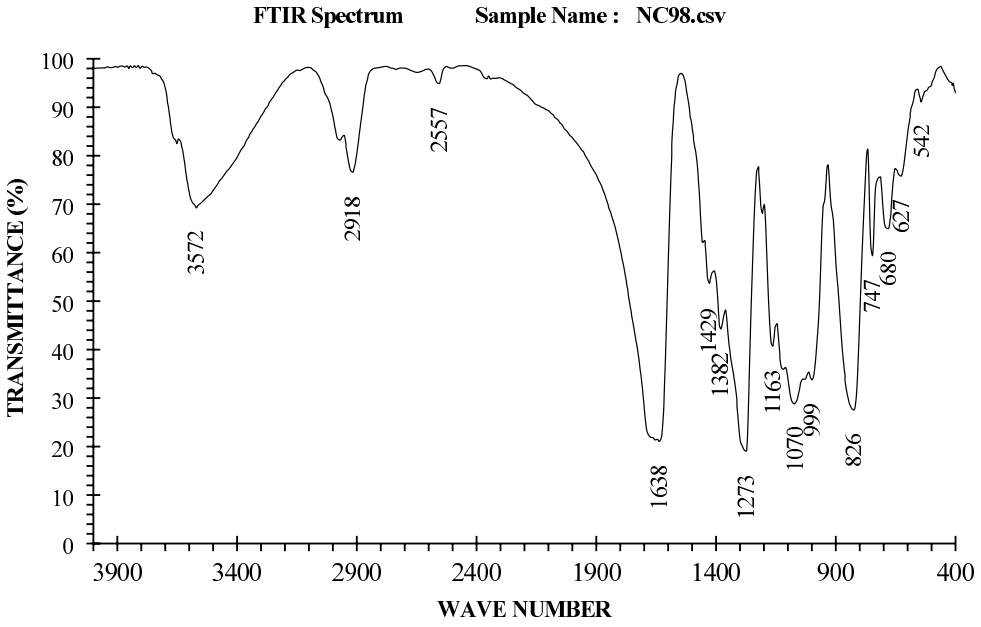


Fig. 2. FT-IR of nitrocellulose prepared of Cotton linters pulp with 98% purity.

shows that only a few hydroxyl groups of cellulose were replaced by nitrous groups and formed nitrocellulose with low nitrogen percent.

GPC result

As can be seen in Figs. 4 and 5, the GPC of nitrocellulose produced from wood pulp with 89% purity under the best conditions (time: 4 min, acid/cellulose:15/1) (55303 Dalton) is similar to nitrocellulose produced of cotton linters pulp with 98% purity (59402 Dalton). Polydispersity is standard for uniformity of Nitrocellulose. Whatever it closer to 1, molecular weight distribution of polymer is good and vice versa. Accordingly seen the

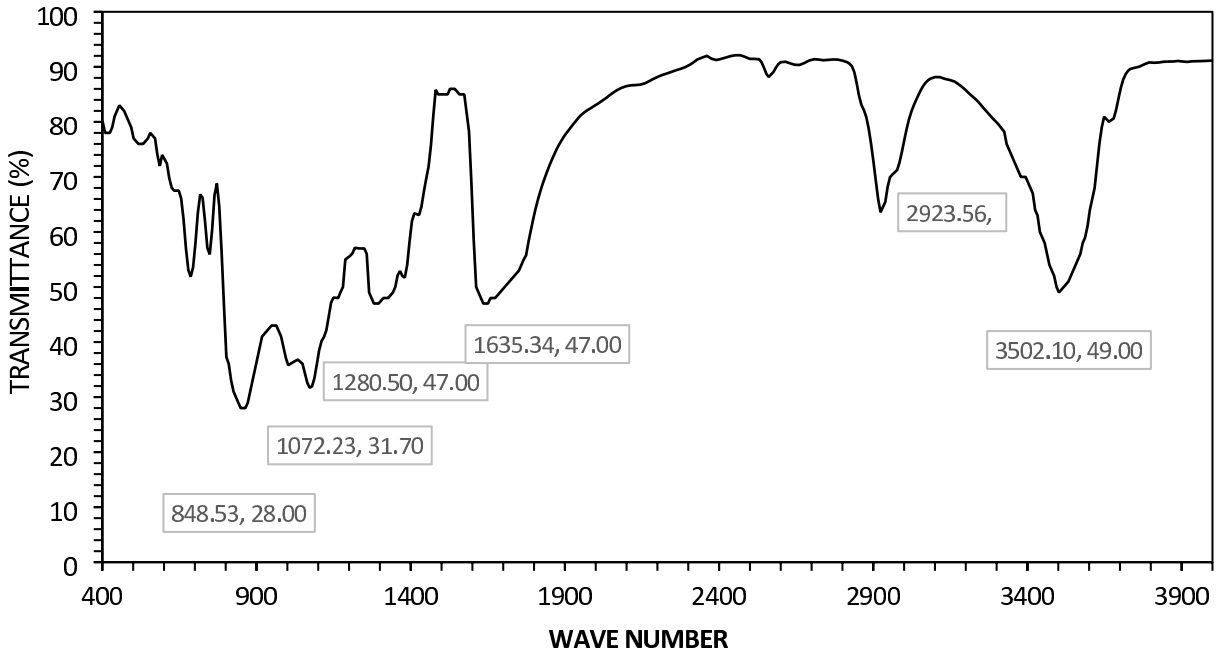
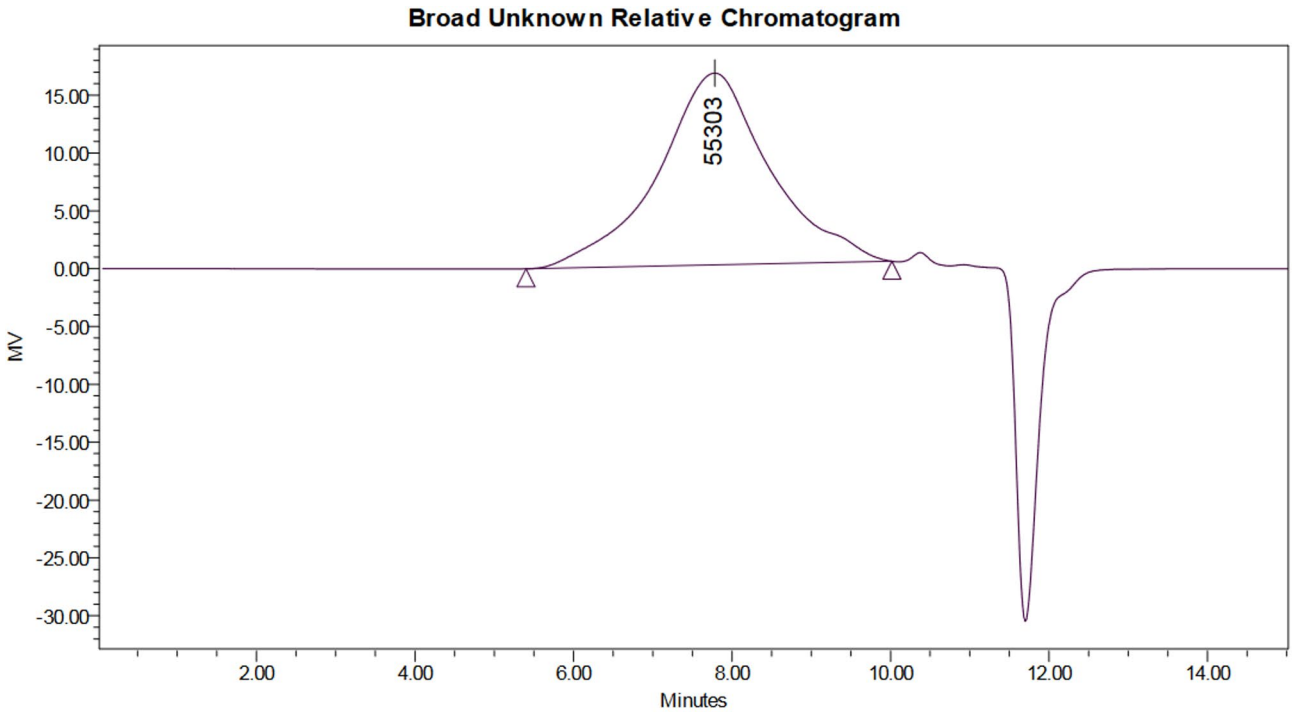


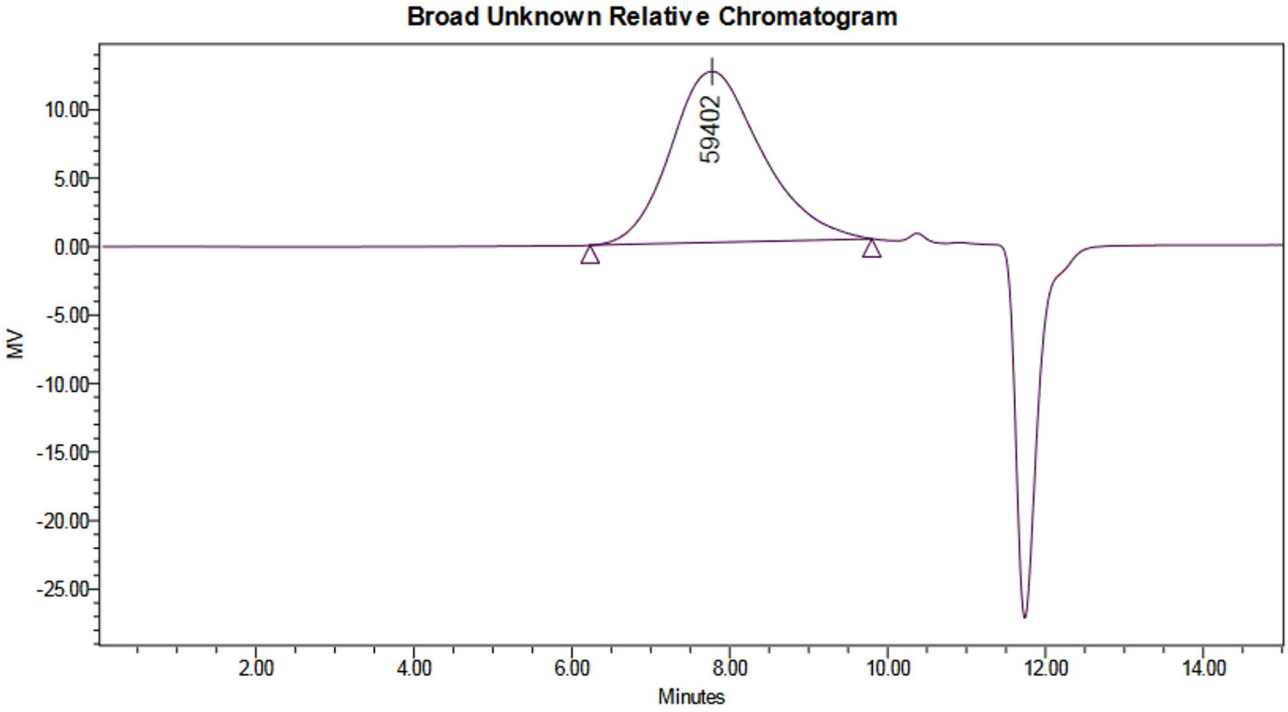
Fig. 3. FT-IR of nitrocellulose prepared of wood pulp with 89% purity after 2 min nitration.



Broad Unknown Relative Peak Table

	Distribution Name	Mn (Daltons)	Mw (Daltons)	MP (Daltons)	Mz (Daltons)	Mz+1 (Daltons)	Polydispersity	Mz/Mw	Mz+1/Mw
1		18895	156305	55303	840930	1807269	8.272367	5.380074	11.562483

Fig. 4. GPC of nitrocellulose prepared of wood pulp with 89% purity from best condition (time: 4 min, acid/cellulose:15/1).



Broad Unknown Relative Peak Table

	Distribution Name	Mn (Daltons)	Mw (Daltons)	MP (Daltons)	Mz (Daltons)	Mz+1 (Daltons)	Polydispersity	Mz/Mw	Mz+1/Mw
1		23295	82708	59402	199483	366101	3.550446	2.411907	4.426443

Fig. 5. Nitrocellulose prepared of cotton linters with 98% purity.

polydispersity of Nitrocellulose from wood pulp with 89% purity from best condition is 8.2 and Nitrocellulose from alpha cellulose cotton linters pulp is 3.5.

DSC result

As can be seen in Figs. 6 and 7, the DSC of nitrocellulose produced from pulp with 89% purity under the best conditions (time: 4 min, acid/cellulose:15/1) is similar to nitrocellulose produced from cotton linters pulp with 98% purity. When the peak of decomposition of nitrocellulose is below 180 ?, it is sensitive to heat, and when it is above 180 ?, its sensitive is the range of standard. As can be seen in the graph, the peak of exothermic is above 180 ?.

Result of XRD spectrum

Studding of XRD spectrum data's shows that it was similar for cotton linters pulp and dissolving wood pulp with 92% purity (Na_6) and for wood pulp sample it was different approximately 20 degrees in angle 2θ diffraction (Fig. 8). Comparing these spectrums with crystalline cellulose shows acceptable conformity for cotton linters pulp and dissolving wood pulp. Only difference is existing of amorphous region in the cotton linters pulp and dissolving wood pulp toward crystalline cellulose. For this amorphous region, there are broad peak in graph. Also, for existing none cellulosic (Hemicellulose) or more percent amorphous region in wood pulp, two peak combines near angle 2θ in approximately 20 degrees.

It can be resulted that there aren't more different XRD Spectrum between wood pulp, cotton linters pulp and dissolving pulp (Figs. 9, 10 and 11).

Based on the positive results of the laboratory and pilot tests, the following plan can be proposed for the industrialization of the technology for the production of nitrocellulose from cellulose sheets, rolls and cotton linters pulp (see in Fig. 12).

Conclusion

This study investigated the use of a new continues nitropulper technology and conventional raw materials in the production of commercial nitrocellulose. This study investigated that opening and nitrating cellulose sheets with nitropulper machine offers more advantages than other sheet opening technologies. It was investigated that the best time for opening and nitrating the sheets is 3, 4and 5 min, so that there is the least dust generation, high production capacity in the nitropulper, high safety, low transportation and less environmental impact. In

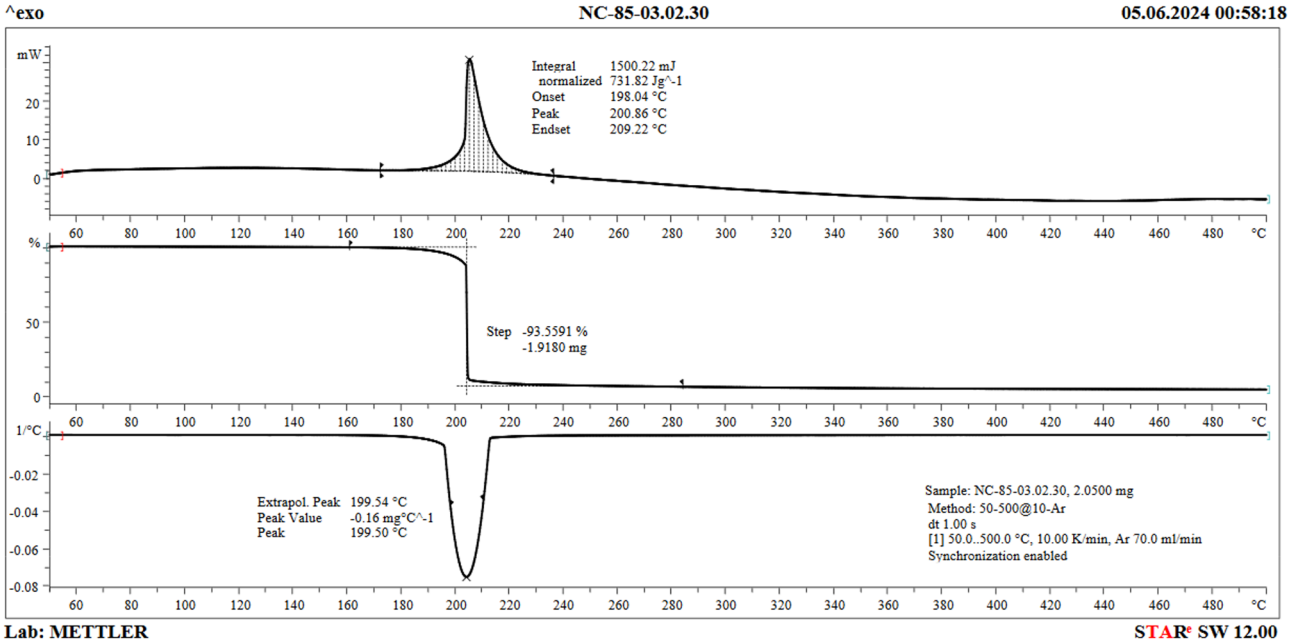


Fig. 6. DSC of nitrocellulose prepared of wood pulp with 89% purity from best condition (time: 4 min, acid/cellulose:15/1).

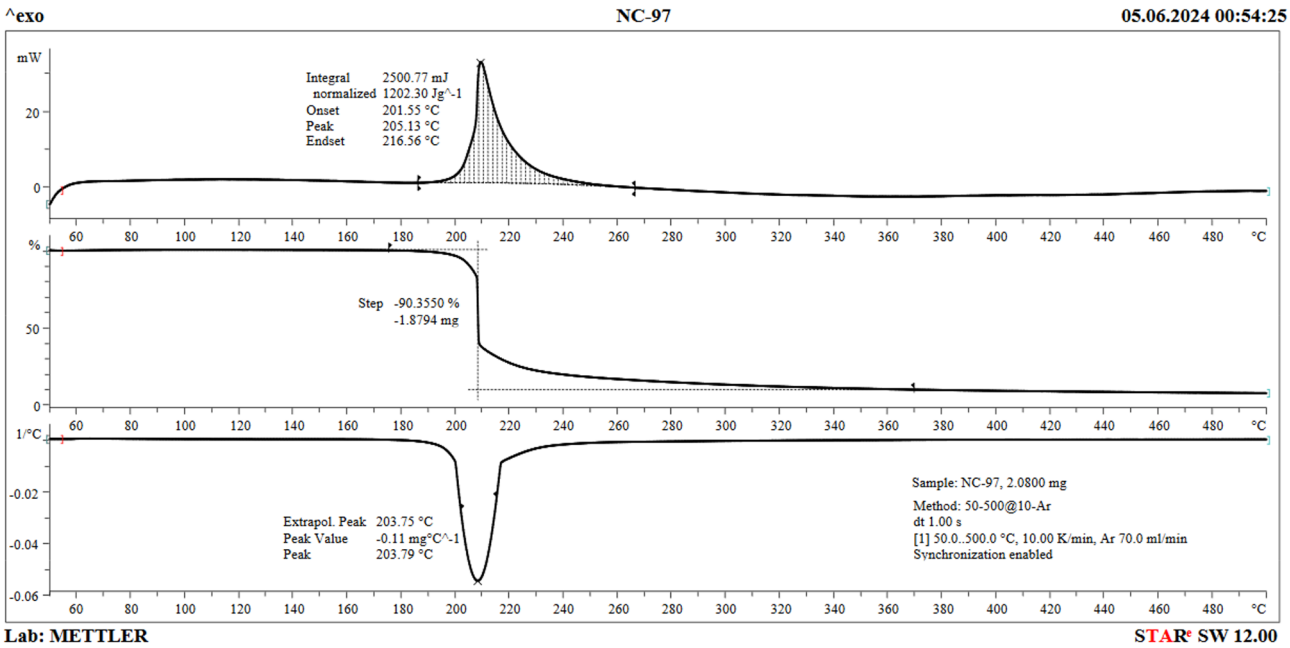


Fig. 7. DSC of nitrocellulose prepared of cotton linters with 98% purity.

addition, the best quality for nitrocellulose fibers and lacquer is achieved in this period. Production capacity has also been increased in the nitrating (75%) and autoclave (63%) stages of the production process. In the acid stage, the passage of the fibers through the slot by centrifugation has been reduced compared to the fluffy state. In addition, acid consumption for nitrating has been reduced (76%), while the cost of processing the sheets has also been lowered (44%). Commercial pulp is available worldwide in large quantities for the production of various types of paper, cardboard, paper towels, baby diapers, sanitary napkins, etc., and its supply is not limited in any country. Its cost is also much lower than that of wood pulp, so the cost of nitrocellulose will be lower by the same amount.

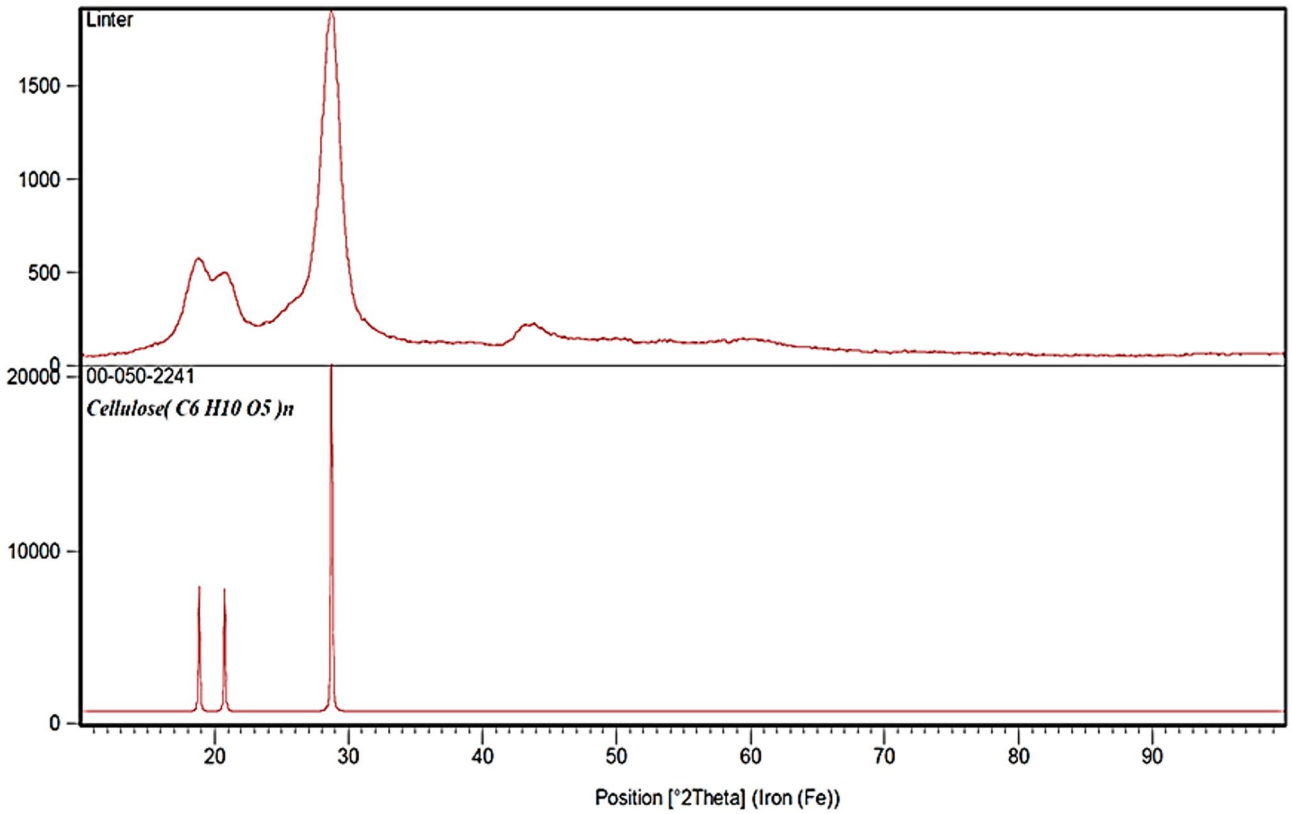


Fig. 8. XRD Cotton linters pulp with 98% purity.

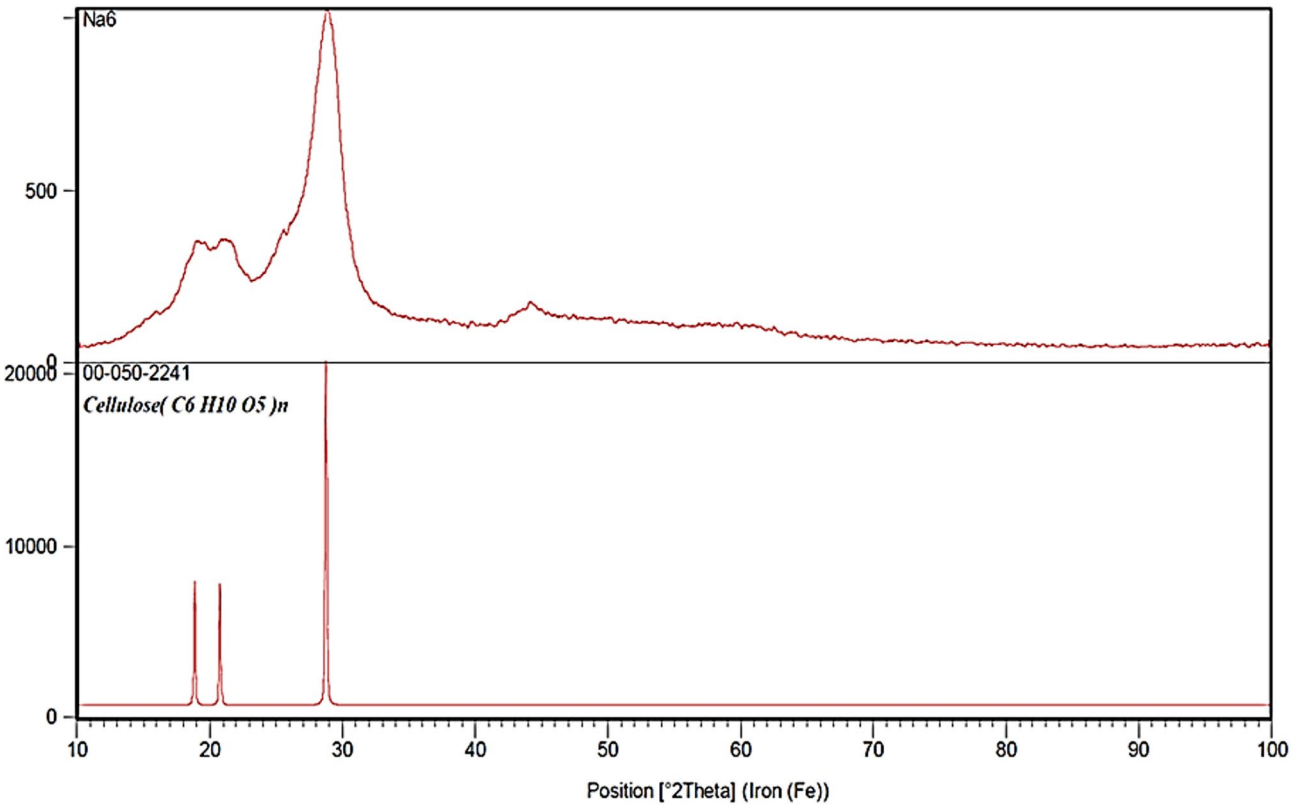


Fig. 9. XRD dissolving wood pulp with 92% purity.

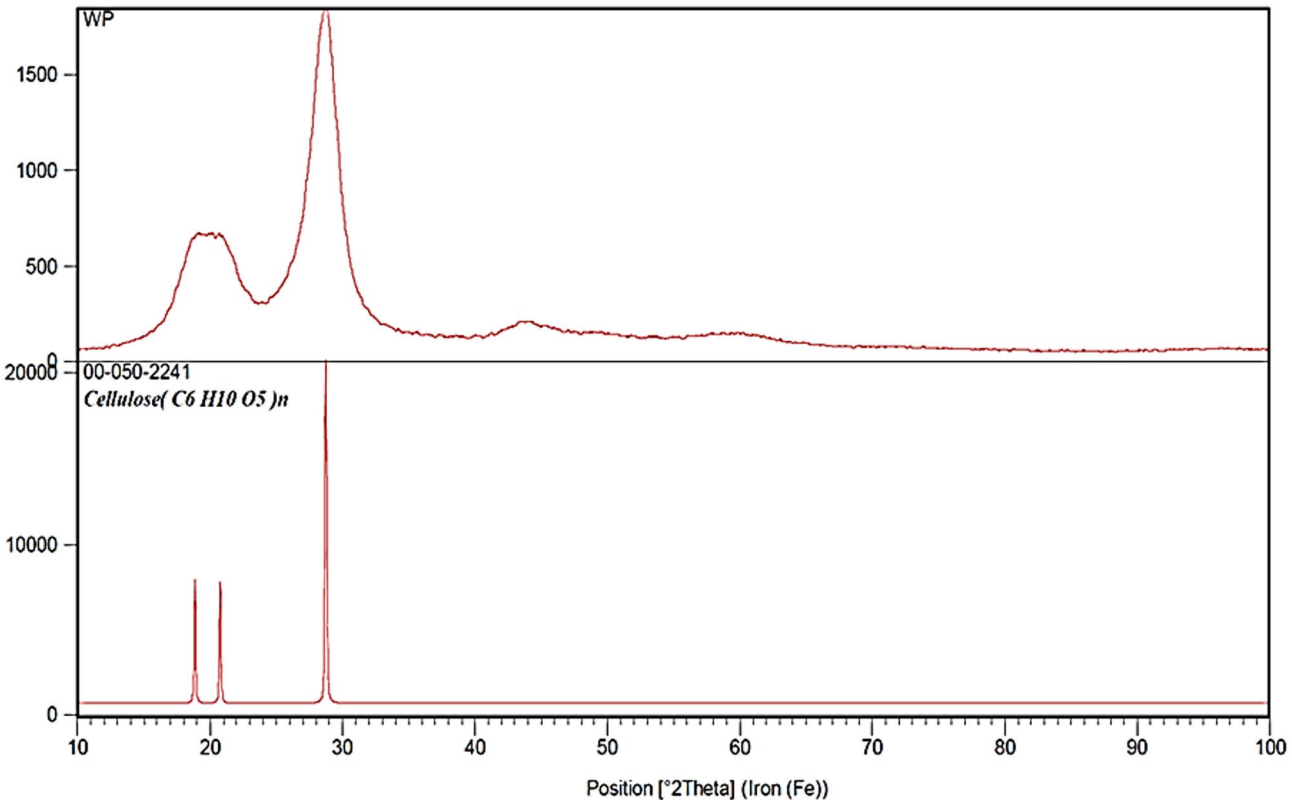


Fig. 10. XRD wood pulp with 89% purity.

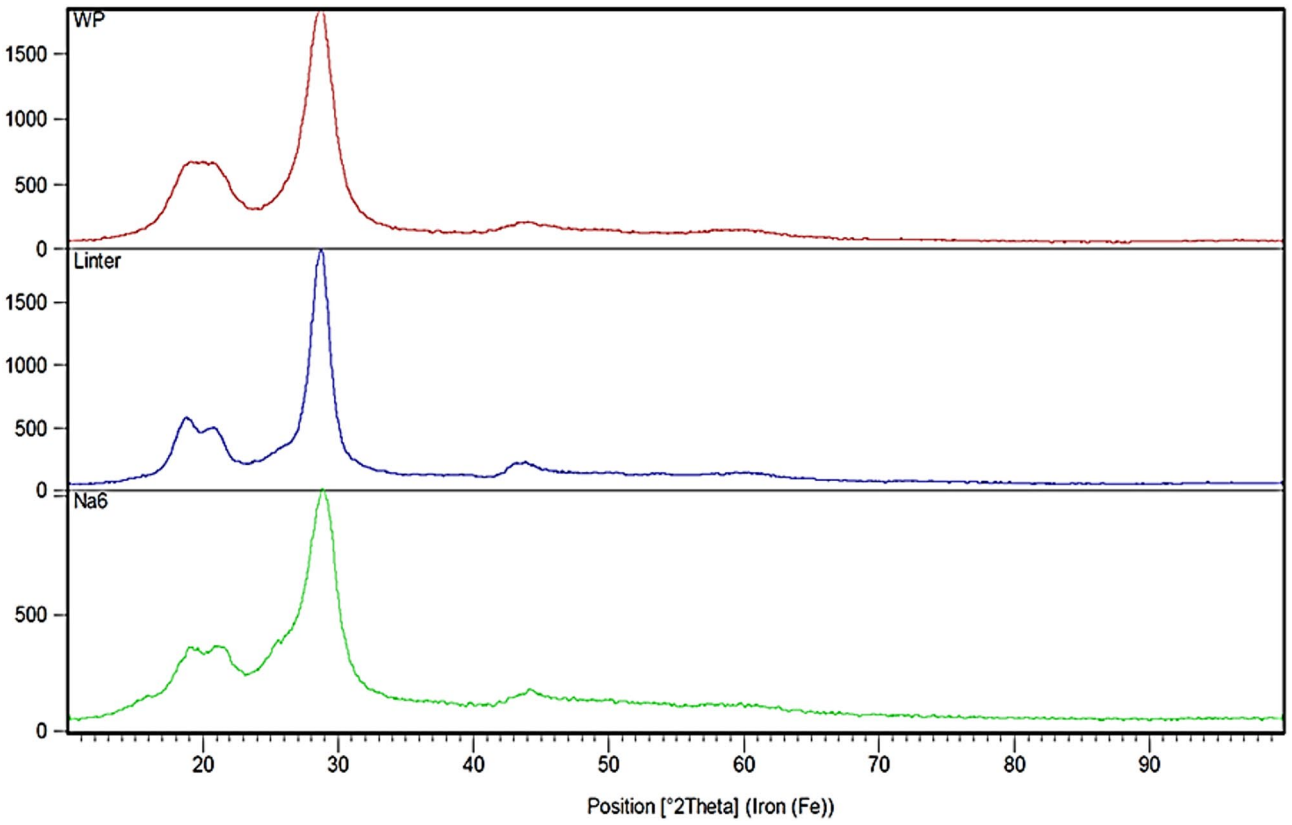


Fig. 11. XRD Cotton linters pulp, dissolving pulp and wood pulp.

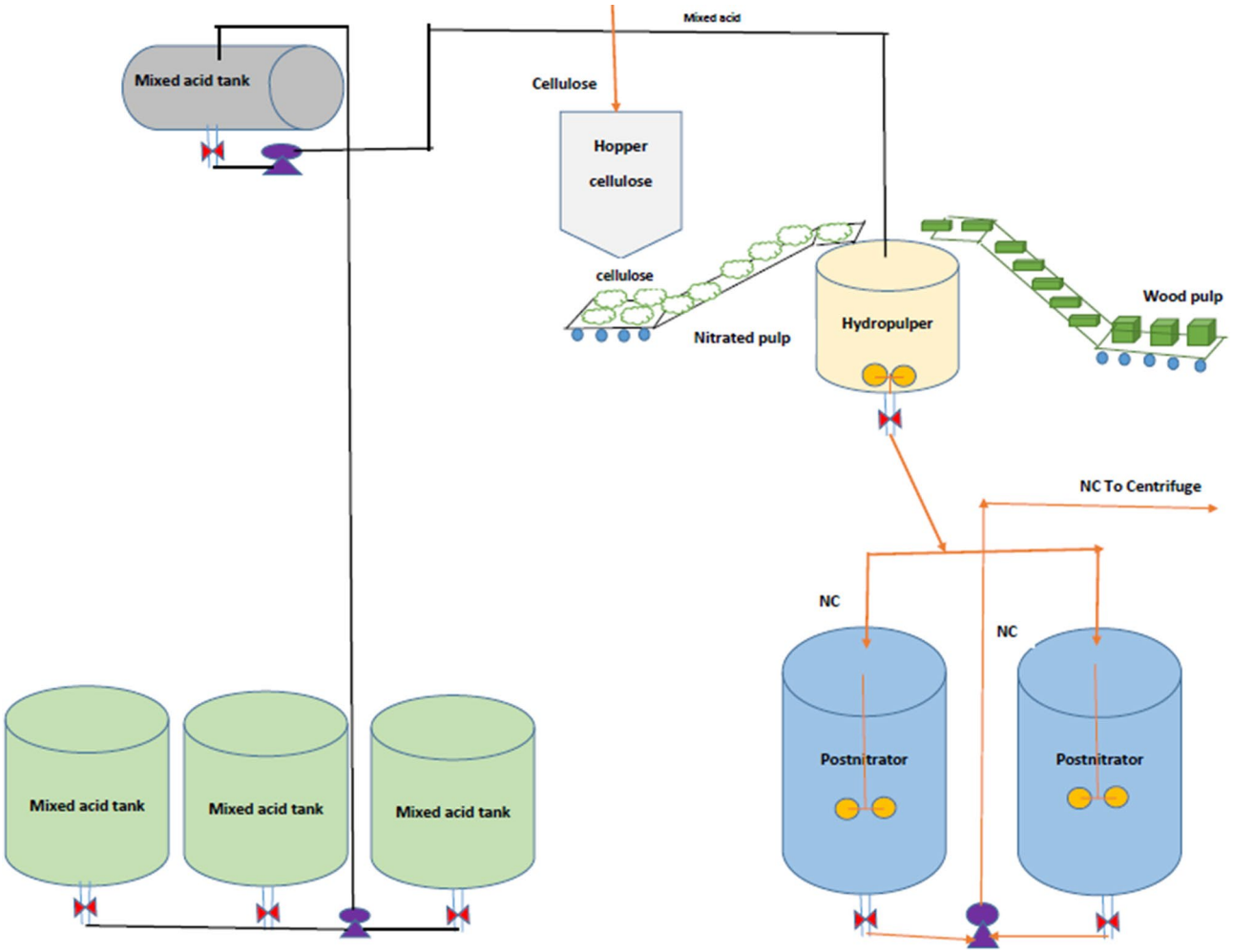


Fig. 12. Process flow diagram for producing of nitrocellulose with nitropulper technology in steps of nitration and boiling.

Data availability

The data supporting this study are available when reasonably requested from the corresponding author.

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Author contributions
All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by all authors.

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Declarations

Competing interests
The authors declare no competing interests.

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This is not applicable in this article.

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