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Possibilities of fractional filtrate configurations Case: Bleaching of wood pulp fibres

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Abstract

Chemical processes often produce filtrate fractions with different chemical and physical properties. Typically filtrate fractions differ in the concentration of dissolved reaction products, reagents, and salts, but they may also differ in pH and temperature. In fractional filtrate configurations these fractions are used separately in earlier stages of the process in a way that ensures the best possible responses for the process.

The purpose of this paper is to make a theoretical and systematic evaluation of the possibilities of different fractional filtrate configurations, i.e. fractional washing concepts, in connection with the improvement of wood pulp fibre bleaching. A washing model was used to simulate dissolved organic and residual chemical material balances in eight different process configurations. Each process configuration represents one single bleaching stage, consisting of a filter washer, a reactor, and a second filter washer in series.

The results demonstrate that fractional filtrate configurations have the potential either to increase washing efficiency for dissolved reaction products, or to increase the recycling ability of the active process chemicals. However, these two goals are contradictory. The results encourage the creation of process machinery and configurations where different filtrate fractions are used differently for specific aims. The idea of fractional filtrate configuration should also be applicable to and beneficial for other branches of the chemical and mineral processing industries.

Keywords: Pulp and paper; Wood fibres; Washing; Filtrates; Recycling; Processes; Simulation; Bleaching

1. Introduction

1.1. Washing of wood pulp fibres

Wood pulp fibres are processed in aqueous chemical processes at various steps including reaction and washing treatments. Washing of wood pulp fibres is typically performed using fresh chemically-treated water or aqueous filtrates from other stages of the process. Washing steps are often counter-currently connected to minimise fresh water consumption and the amount of effluents produced in the process.

There are two basic ways to perform washing of wood pulp fibres on industrial scale, namely displacement washing and dilution-thickening washing [1]. In displacement washing the liquor in the fibre mat is displaced with fresh water or cleaner filtrate. The wash liquor remains in the fibre mat and most of the original liquor runs out of the mat. Ideally, if no mixing of liquors takes place, it is possible to remove all the original liquor by displacing with one volume of wash liquor [1,2]. Displacement washing is applied industrially in filter and diffuser-type washers.

In dilution-thickening washing, the fibre slurry is diluted and thoroughly mixed with fresh water or clean filtrate, and then thickened by filtering or by pressing. Dilution-thickening does not remove all the dirty original liquor from the fibre suspension unless it is repeated many times using fresh water. The efficiency of dilution-thickening washing depends primarily on the consistencies to which the fibres are diluted and thickened [1,2]. Dilution-thickening washing is applied industrially in different types of press washers.

1.2. Configurations applied to bleaching of wood fibres

The washing of wood pulp fibres in connection to bleaching has two clear aims. Firstly, dissolved organic reaction products and impurities left over from the previous chemical

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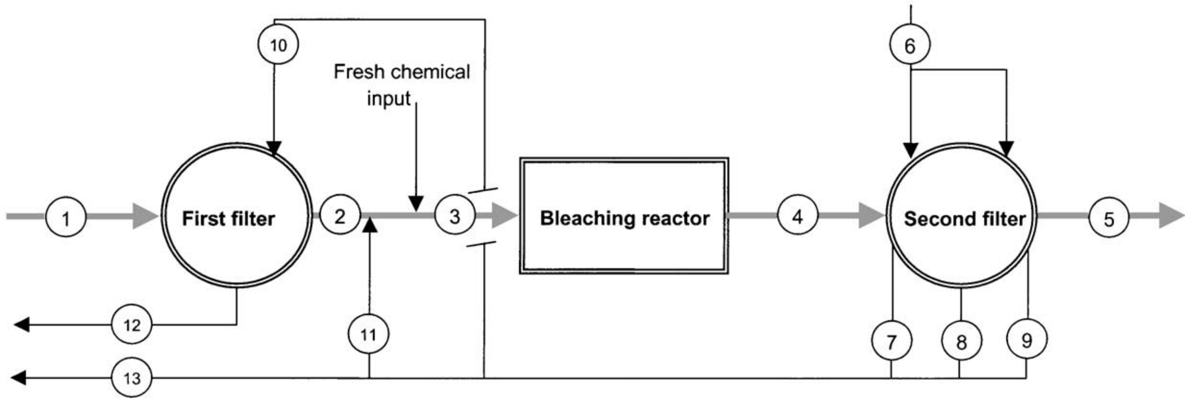

Fig. 1. Flow sheet for Configuration 1 (numbers 1–13 refer to Table 1).

treatment should be removed. Secondly, wood pulp fibres should be prepared chemically (pH, residual chemical and metal contents) and physically (temperature, consistency) for the following process treatment. This modification of fibres takes place partly during the washing operation [2,3].

A basic process configuration around a single bleaching stage consists of a reactor, and one washing stage before and one after the reactor. Part of the filtrate from the latter washing stage is typically recycled to dilute the fibres just before the reactor and is used as wash liquor in the previous washing stage (Fig. 1). Thus, the fibre suspension and filtrate flows move counter-currently through the bleaching stage [2]. It should be possible to improve bleaching process behaviour fundamentally by modifying this basic filtrate configuration.

Tervola et al. [4] described an interesting concept of improving displacement washing by fractional washing. Their idea was to divide the filtrate from the latter part of the process into two fractions and to use them separately in earlier stages of washing. Kokkonen and Qvintus [5] had earlier modified a single pressurised filter washer to operate using different liquor fractions in multi-stage brown stock washing. After a period of practical development work they also studied the theoretical background for this kind of a filtrate configuration [6]. During the 90s, the fractional filtrate concept was implemented in kraft cooking [7], post-oxygen washing [8,9] and in bleaching of wood fibres [10–12]. The earlier studies had concentrated on increasing washing efficiency, removing some harmful components out of the system and reducing the amount of fresh water required.

The purpose of the present study was to make a theoretical and systematic evaluation of the possibilities of fractional filtrate configurations in connection to one single bleaching stage in the bleaching of wood pulp fibres. Special attention is paid to the percentage changes in the washing results and to the recyclability of valuable residual chemicals back to the process.

2. Methods

2.1. Process configurations

This study was made by comparing simulated dissolved organic and residual chemical material balances in eight different process configurations. All the process configurations represented a single bleaching stage, and each of them consisted of a bleaching reactor and two filter washers. The first filter washer was located before the reactor and the second filter immediately after the reactor (Fig. 1).

Three different filtrate fractions were available from the second filter washer. The first filtrate fraction, the thickening filtrate, was the result of a thickening operation, i.e. increasing fibre consistency in the washer before the actual displacement. The second filtrate fraction originated from the first displacement zone of the washer, and the third filtrate fraction from the second displacement zone. Some additions of filtrate were needed in earlier stages of the process, i.e. for diluting the fibres before the bleaching reactor and for washing the wood fibres in the first filter. The rest of the filtrate from the second filter was sewered. An addition of fresh chemicals was assumed just before the reactor and some organic material was dissolved as reaction products during the bleaching reactions. All eight process configurations used the same process equipment located in the same position in the configuration, and all the configurations used the same amount of fresh water. The configurations differed in the way the three different filtrate fractions were used in earlier stages of the process. The process configurations considered are listed below and the corresponding process flow strategies are shown in Figs. 1–8.

Configuration 1 (Fig. 1) represents the basic process configuration with a non-fractional filtrate circulation system in bleaching. All three filtrate fractions are collected and mixed together in the second filter filtrate tank before being used for washing and dilution.

Configuration 2 (Fig. 2) is the process whereby the thickening filtrate and the filtrate from the first displacement zone

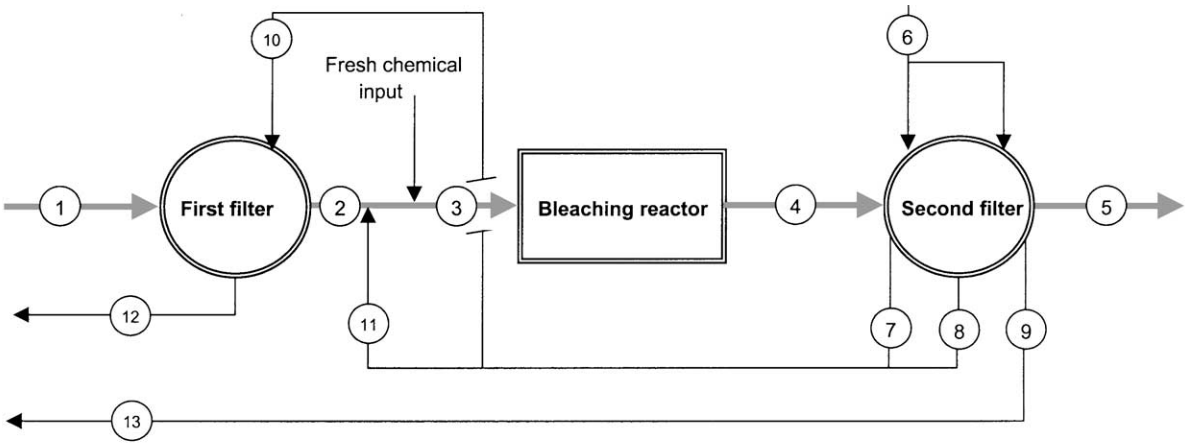

Fig. 2. Flow sheet for Configuration 2.

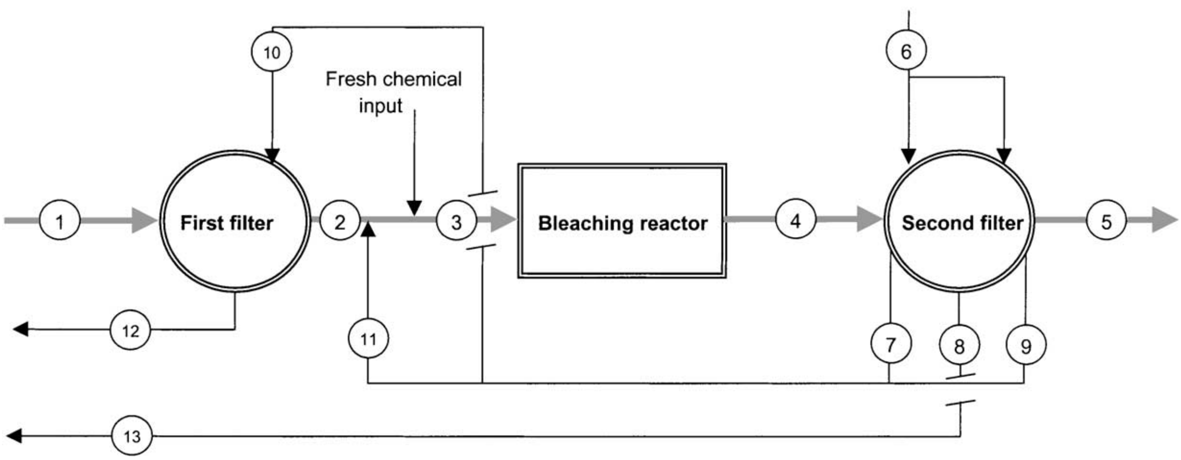

Fig. 3. Flow sheet for Configuration 3.

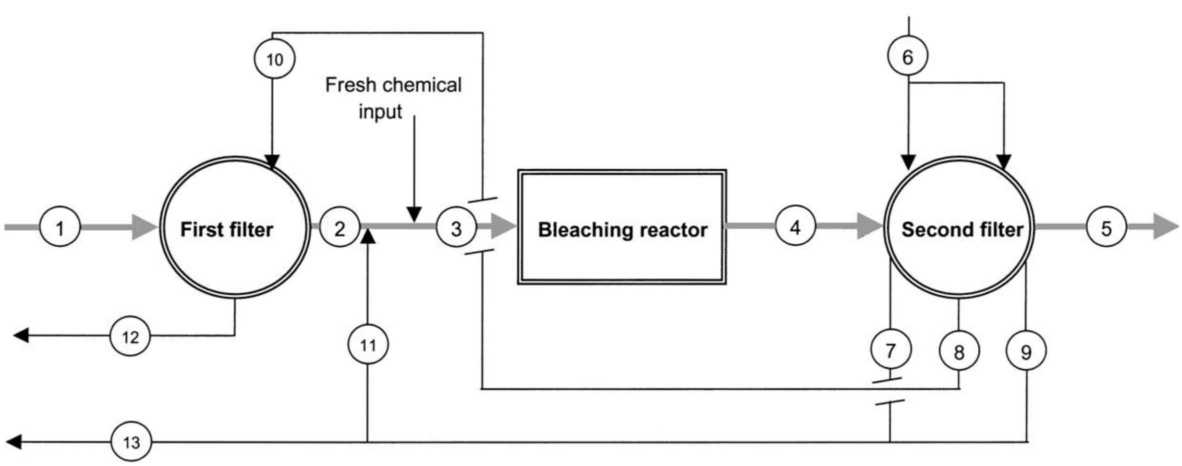

Fig. 4. Flow sheet for Configuration 4.

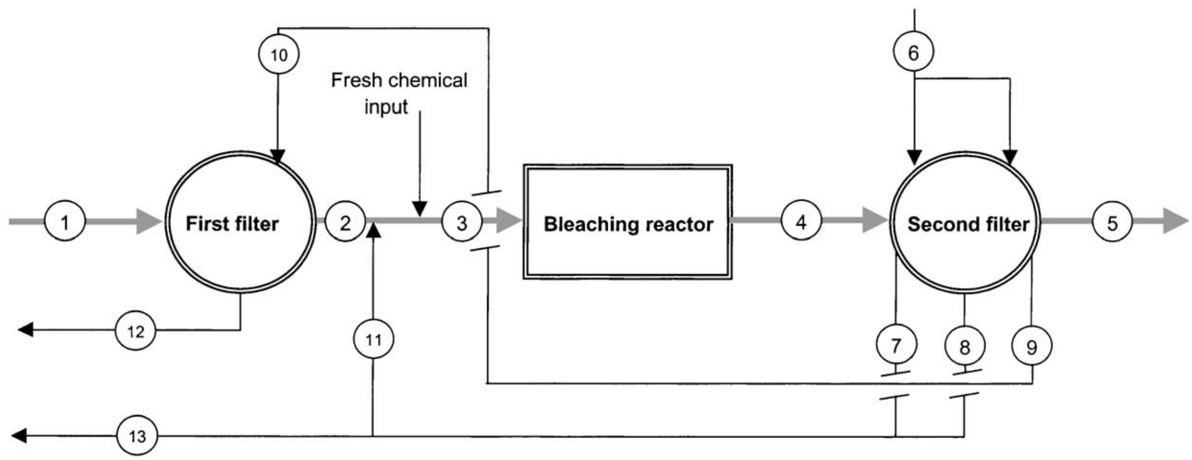

Fig. 5. Flow sheet for Configuration 5.

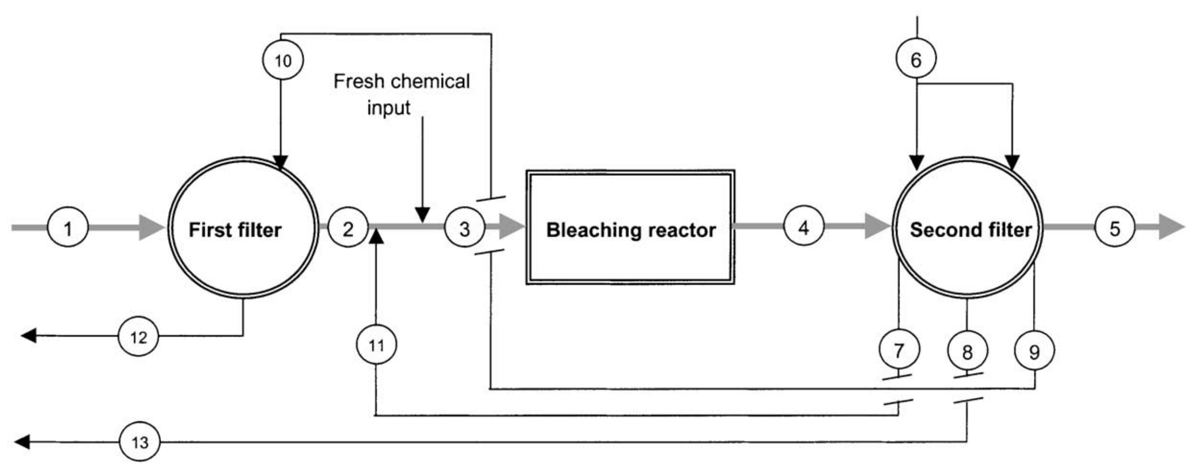

Fig. 6. Flow sheet for Configuration 6.

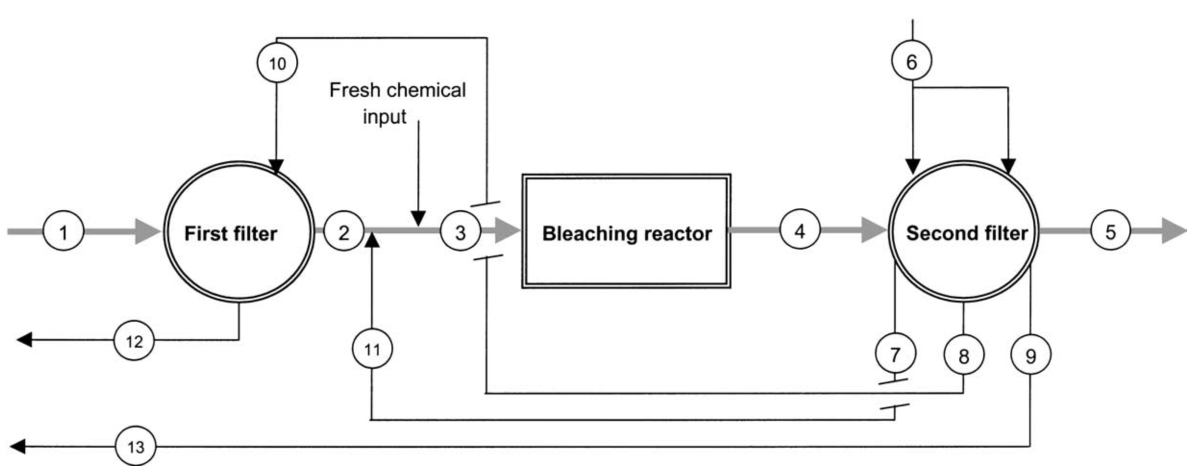

Fig. 7. Flow sheet for Configuration 7.

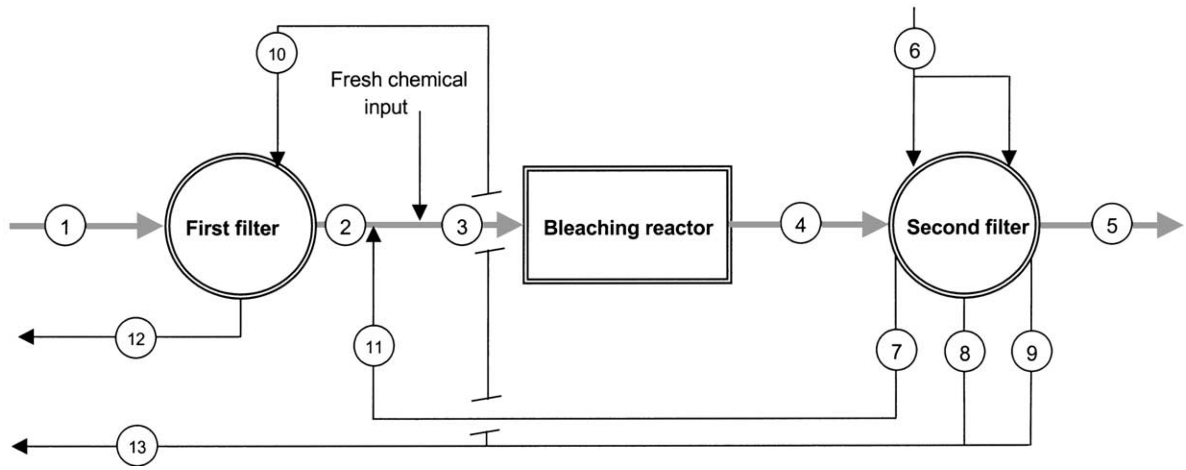

Fig. 8. Flow sheet for Configuration 8.

are collected, mixed and used for washing and dilution. The filtrate from the second displacement zone is sewered.

Configuration 3 (Fig. 3) resembles Configuration 2, but the filtrates from the first and second displacement zones are reversed. The filtrate from the second displacement zone is mixed with the thickening filtrate and used for washing and dilution. The filtrate from the first displacement zone is sewered.

Configuration 4 (Fig. 4) is a process whereby the filtrate fractions are formed in a similar way to Configuration 3, but are used differently. The filtrate from the first displacement zone is used for washing. The mixture of the other two fractions is partly used for dilution and partly sewered.

Configuration 5 (Fig. 5) resembles Configuration 4, but the filtrates from the first and second displacement zones are reversed. The filtrate from the second displacement zone is used alone for washing. The mixture of the other fractions is partly used for dilution and partly sewered.

Configuration 6 (Fig. 6) is a process whereby all three filtrate fractions are used separately. The thickening filtrate is used for dilution. The filtrate from the first displacement zone is sewered. The filtrate from the second displacement zone is used for washing.

Configuration 7 (Fig. 7) resembles Configuration 6, but the filtrate from the first and the second displacement zones are reversed. The filtrate from the first displacement zone is used for washing and the filtrate from the second displacement zone is sewered.

Configuration 8 (Fig. 8) is a process whereby the thickening filtrate is used for dilution, and the mixed liquor from the other two fractions is partly used for washing and partly sewered.

2.2. Simulations

The simulations were carried out using PulpSim 14, a commercial energy and material balance program. PulpSim is a Fortran-based code operating in an AutoCad environment [13]. PulpSim gives an iterative mathematical result for the energy and material balance of a particular process configuration. The actual modelling behind the washing simulations is based on the chemical engineering theories applied to pulp and paper manufacturing [1,2,14]. The process configurations and washing calculation procedures were formed using ready-made unit operations and department blocks in the software. Displacement operation calculations are explained in more detail in the Appendix A.

The fibres fed to the first filter were clean, i.e. without any organic or residual chemical contamination. This assumption, although it is not realistic in practice, was made in order to estimate the effect of the material dissolved or charged in one particular bleaching stage. The fibre consistencies were 10 mass% to the reactor and 15 mass% to and after the displacement washing units in both filters. The amount of fresh wash water, i.e. with a concentration of 0, was 8.16 m^3/bdmt (bone dry metric ton of pulp) corresponding to a dilution factor of 2.5 m^3/bdmt (see definition in [1]). The first filter washer used half of the amount of wash liquor compared with the second filter, thereby producing a negative dilution factor. The amounts of organic material formed in the reactor and fresh chemical input were normalised to 100 mass units (i.e. kg or g). The chemical consumption was assumed to be 30% during the bleaching reactions. It was assumed that both the organic material and the residual chemicals were totally dissolved in the liquors, which seems fairly realistic with regard to pulp fibre bleaching.

3. Results

3.1. Results in general

Material balances for eight different process configurations were simulated and the dissolved organic and residual

Table 1
The amounts of liquor, the simulated material loads, and concentrations at each position

		Amount of liquor (m^3/bdmt)	Residual chemical		Dissolved organic material	
			Load (mass/bdmt)	Concentration (mass/m^3)	Load (mass/bdmt)	Concentration (mass/m^3)
Configuration 1						
1	Feed to the first filter	5.67	0	0.0	0	0.0
2	Discharge from the first filter	5.67	34	6.0	67	11.8
3	Feed to bleaching reactor	9.00	165	18.3	128	14.2
4	Feed to the second filter	9.00	115	12.8	228	25.3
5	Discharge from the second filter	5.67	10	1.7	19	3.4
6	Wash water to the second filter	8.16	0	0.0	0	0.0
7	Thickening filtrate	3.33	43	12.8	84	25.3
8	Filtrate from the first displacement zone	4.08	43	10.4	84	20.6
9	Filtrate from the second displacement zone	4.08	20	5.0	40	9.8
10	Wash liquor to the first filter	4.08	38	9.2	74	18.1
11	Dilution liquor	3.33	31	9.2	60	18.1
12	Filtrate from the first filter	4.08	4	0.9	7	1.7
13	Filtrate to sewer	4.08	38	9.2	74	18.1
Configuration 2						
1	Feed to the first filter	5.67	0	0.0	0	0.0
2	Discharge from the first filter	5.67	51	9.0	124	21.8
3	Feed to bleaching reactor	9.00	197	21.8	235	26.1
4	Feed to the second filter	9.00	138	15.3	335	37.2
5	Discharge from the second filter	5.67	12	2.0	28	4.9
6	Wash water to the second filter	8.16	0	0.0	0	0.0
7	Thickening filtrate	3.33	51	15.3	124	37.2
8	Filtrate from the first displacement zone	4.08	51	12.4	124	30.3
9	Filtrate from the second displacement zone	4.08	24	6.0	59	14.5
10	Wash liquor to the first filter	4.08	56	13.7	136	33.4
11	Dilution liquor	3.33	46	13.7	111	33.4
12	Filtrate from the first filter	4.08	5	1.3	13	3.1
13	Filtrate to sewer	4.08	24	6.0	59	14.5
Configuration 3						
1	Feed to the first filter	5.67	0	0.0	0	0.0
2	Discharge from the first filter	5.67	30	5.3	57	10.0
3	Feed to bleaching reactor	9.00	157	17.4	108	12.0
4	Feed to the second filter	9.00	110	12.2	208	23.1
5	Discharge from the second filter	5.67	9	1.6	17	3.1
6	Wash water to the second filter	8.16	0	0.0	0	0.0
7	Thickening filtrate	3.33	41	12.2	77	23.1
8	Filtrate from the first displacement zone	4.08	41	10.0	77	18.8
9	Filtrate from the second displacement zone	4.08	19	4.8	37	9.0
10	Wash liquor to the first filter	4.08	33	8.1	63	15.3
11	Dilution liquor	3.33	27	8.1	51	15.3
12	Filtrate from the first filter	4.08	3	0.8	6	1.4
13	Filtrate to sewer	4.08	41	10.0	77	18.8
Configuration 4						
1	Feed to the first filter	5.67	0	0.0	0	0.0
2	Discharge from the first filter	5.67	40	7.0	80	14.1
3	Feed to bleaching reactor	9.00	169	18.7	139	15.4
4	Feed to the second filter	9.00	118	13.1	239	26.5
5	Discharge from the second filter	5.67	10	1.7	20	3.5
6	Wash water to the second filter	8.16	0	0.0	0	0.0
7	Thickening filtrate	3.33	44	13.1	88	26.5
8	Filtrate from the first displacement zone	4.08	44	10.7	88	21.6
9	Filtrate from the second displacement zone	4.08	21	5.1	42	10.3
10	Wash liquor to the first filter	4.08	44	10.7	88	21.6
11	Dilution liquor	3.33	29	8.7	59	17.6
12	Filtrate from the first filter	4.08	4	1.0	8	2.0
13	Filtrate to sewer	4.08	36	8.7	72	17.6

Table 1 (*Continued*)

		Amount of liquor (m^3/bdmt)	Residual chemical		Dissolved organic material	
			Load (mass/bdmt)	Concentration (mass/m^3)	Load (mass/bdmt)	Concentration (mass/m^3)
Configuration 5						
1	Feed to the first filter	5.67	0	0.0	0	0.0
2	Discharge from the first filter	5.67	17	3.0	32	5.6
3	Feed to bleaching reactor	9.00	153	17.0	97	10.8
4	Feed to the second filter	9.00	107	11.9	197	21.9
5	Discharge from the second filter	5.67	9	1.6	16	2.9
6	Wash water to the second filter	8.16	0	0.0	0	0.0
7	Thickening filtrate	3.33	40	11.9	73	21.9
8	Filtrate from the first displacement zone	4.08	40	9.7	73	17.8
9	Filtrate from the second displacement zone	4.08	19	4.6	35	8.5
10	Wash liquor to the first filter	4.08	19	4.6	35	8.5
11	Dilution liquor	3.33	36	10.7	66	19.7
12	Filtrate from the first filter	4.08	2	0.4	3	0.8
13	Filtrate to sewer	4.08	44	10.7	80	19.7
Configuration 6						
1	Feed to the first filter	5.67	0	0.0	0	0.0
2	Discharge from the first filter	5.67	18	3.1	34	6.0
3	Feed to bleaching reactor	9.00	159	17.7	113	12.5
4	Feed to the second filter	9.00	111	12.4	213	23.7
5	Discharge from the second filter	5.67	9	1.6	18	3.1
6	Wash water to the second filter	8.16	0	0.0	0	0.0
7	Thickening filtrate	3.33	41	12.4	79	23.7
8	Filtrate from the first displacement zone	4.08	41	10.1	79	19.3
9	Filtrate from the second displacement zone	4.08	20	4.8	38	9.2
10	Wash liquor to the first filter	4.08	20	4.8	38	9.2
11	Dilution liquor	3.33	41	12.4	79	23.7
12	Filtrate from the first filter	4.08	2	0.5	4	0.9
13	Filtrate to sewer	4.08	41	10.1	79	19.3
Configuration 7						
1	Feed to the first filter	5.67	0	0.0	0	0.0
2	Discharge from the first filter	5.67	46	8.2	113	20.0
3	Feed to bleaching reactor	9.00	197	21.9	238	26.5
4	Feed to the second filter	9.00	138	15.3	338	37.6
5	Discharge from the second filter	5.67	12	2.0	28	5.0
6	Wash water to the second filter	8.16	0	0.0	0	0.0
7	Thickening filtrate	3.33	51	15.3	125	37.6
8	Filtrate from the first displacement zone	4.08	51	12.5	125	30.6
9	Filtrate from the second displacement zone	4.08	24	6.0	60	14.7
10	Wash liquor to the first filter	4.08	51	12.5	125	30.6
11	Dilution liquor	3.33	51	15.3	125	37.6
12	Filtrate from the first filter	4.08	5	1.2	12	2.9
13	Filtrate to sewer	4.08	24	6.0	60	14.7
Configuration 8						
1	Feed to the first filter	5.67	0	0.0	0	0.0
2	Discharge from the first filter	5.67	31	5.4	65	11.4
3	Feed to bleaching reactor	9.00	176	19.6	162	18.0
4	Feed to the second filter	9.00	123	13.7	262	29.1
5	Discharge from the second filter	5.67	10	1.8	22	3.9
6	Wash water to the second filter	8.16	0	0.0	0	0.0
7	Thickening filtrate	3.33	46	13.7	97	29.1
8	Filtrate from the first displacement zone	4.08	46	11.2	97	23.7
9	Filtrate from the second displacement zone	4.08	22	5.3	46	11.3
10	Wash liquor to the first filter	4.08	34	8.3	71	17.5
11	Dilution liquor	3.33	46	13.7	97	29.1
12	Filtrate from the first filter	4.08	3	0.8	7	1.6
13	Filtrate to sewer	4.08	34	8.3	71	17.5

chemical material contents of liquors in various positions along one single bleaching stage were calculated. The process positions for the simulated fibre suspensions were as follows (Fig. 1): feed to the first filter (1), discharge from the first filter (2), feed to the bleaching reactor (3), feed to the second filter (4), discharge from the second filter (5). The process positions for the simulated liquor samples were as follows: wash water to the second filter (6), thickening filtrate (7), filtrate from the first displacement zone (8), filtrate from the second displacement zone (9), wash liquor to the first filter (10), dilution liquor (11), filtrate from the first filter (12), and filtrate to sewer (13). Table 1 shows the amounts of liquor, simulated material amounts and concentrations at each position for all eight different process configurations.

3.2. Comparison of the configurations

The basic process configuration, representing the non-fractional way to connect filtrate flows in connection to the bleaching of wood fibres (Fig. 1), was used as a reference against which the other configurations were compared. The material balance for the reference showed that 81% of the dissolved organic material, i.e. formed reaction products, were removed from fibres in the following washing stage (Table 1). Thus 19 units of the reaction products followed the washed fibres to the following process treatment as "carry over" or "washing loss". Recycling of the filtrate back to the earlier stages of the process increased the amount of active chemicals present in the reactor by 65% compared with the fresh chemical input of 100 units. Half of this increase was due to the dilution and half to the residual chemicals recycled to the washing in the first filter. The amount of dissolved organic material increased by 128 units in the reactor compared to the amount of reaction products formed in the bleaching reactions. The concentrations of the three filtrate fractions in the second filter differed from each other (Table 1). The thickening filtrate (7) had the highest concentration, being 20% higher than the filtrate from the first displacement zone (8). The filtrate from the second displacement zone (10) had only half the concentration of the other two filtrate fractions.

There were two general trends in the simulation results compared to the reference. Some configurations improved the washing result, i.e. increased the washing efficiency (Configurations 3, 5 and 6), and some increased the amount of active chemicals present in the bleaching reactor (Configurations 2, 7 and 8). The results for Configuration 4 were almost equal to those for the basic process configuration.

The results for Configurations 2 and 7 showed the lowest washing efficiency, i.e. the highest amount of dissolved organic material after the second filter, with the same amount of fresh water as the basic reference process configuration (Configuration 1). The washing result for dissolved organic material was as high as 28 units. However, the results showed high recycling ability for active residual chemicals back to the bleaching reactor. The amount of active chemicals present in the reactor (197 units) almost doubled compared with the fresh input (100 units) and it was clearly higher than in the basic process configuration (165 units). The amount of dissolved organic material going to the bleaching reactor also increased considerably, from 128 to 235/238 units.

Configuration 5 showed the best washing efficiency, but in contrast, also the lowest recyclability. The washing result was 16 units, which was 3 units lower than for the reference. The amount of active chemical present in the bleaching reactor was 153, which was 12 units lower than the reference and 44 units lower than Configuration 2. The main difference between Configurations 5 and 7 was that the filtrate with the highest possible content of dissolved-material was sewered in Configuration 5, i.e. was not used as wash or dilution liquor ahead of the bleaching reactor. This fact had a positive effect on the washing efficiency.

4. Discussion

Good washing between separate bleaching treatments allows higher quality, stable production and low consumption of bleaching chemicals. Good washing means removing reaction products and impurities left from the previous treatment and modifying the fibres chemically and physically for the following treatments [2,3]. The basic counter-current water circulation principle is known both theoretically and practically to be an efficient way to achieve high recovery of chemicals and low dissolved-material carry over to the following process treatment stage. Some of the filtrates are recycled to achieve lower fresh water consumption and lower fibre consistency in each step of the process. In the case of recycling, some additional active chemicals are recovered and returned to the reactor. However, some additional reaction products are also collected and returned to the reactor.

Interesting theoretical and practical possibilities arise for new process modifications when different filtrate fractions are available in the process. This study used a systematic simulation approach to show examples of responses when fractional filtrate configurations are used in connection to wood pulp fibre bleaching. Some modifications clearly improved washing efficiency (Configurations 3 and 5) and some clearly improved the recycling ability (Configurations 2 and 7). These two improvements were not maximised in the same configuration as they are contradictory to each other. Thus one has to choose which improvement to pursue.

Fractional filtrate configuration is now a reality with regard to wood pulp fibre processing [5,6,9–12]. Fractional process configurations are often designed in order to improve washing efficiency and to reduce fresh water consumption. The fractional filtrate configurations applied in bleaching resemble Configuration 5 [10–12]. When possible, both filtrate fractions from the second filter washer are used for washing rather than being sewered. This is especially the case in earlier stages of wood pulp fibre processing (brown stock washing, post-oxygen washing) [5,6,8].

Table 2
A sensitivity analysis for Configurations 1, 5 and 7

Washing efficiency in the second filter	Consistency in the reactor (%)	Fibre consistency in both filters (%)	Dilution factor in the second filter (m^3/bdmt)	Chemical consumption in bleaching reactions (%)	Feed to the bleaching reactor (residual chemical, load (mass/bdmt))			Discharge from the second filter (dissolved organic material, load (mass/bdmt))		
					Configuration 1	Configuration 5	Configuration 7	Configuration 1	Configuration 5	Configuration 7
1.15	10	15	2.5	30	165	153	197	19	16	28
1.00	10	15	2.5	30	163	152	195	21	19	31
1.50	10	15	2.5	30	167	154	202	15	13	23
1.15	8	15	2.5	30	180	171	216	18	16	28
1.15	12	15	2.5	30	152	138	181	20	17	28
1.15	10	12	2.5	30	150	136	175	24	20	32
1.15	10	15	1.3	30	166	157	191	26	24	36
1.15	10	15	4.2	30	161	147	202	11	10	20
1.15	10	15	2.5	10	202	180	273	19	16	28
1.15	10	15	2.5	70	120	117	127	19	16	28

Fractional filtrate configuration has also been utilised by performing partial washing stages in a single washer (1.5 washing stages) [9–12]. Such a system further improves washing efficiency in that particular process position.

There are no special applications at present where fractional filtrate configuration is used to maximise the recycling ability for some valuable chemical in the process. According to the results of this study, maximising the recycling ability means a decrease in washing efficiency. However, washing efficiency can be improved by adding new washing stages, even in a single washer. The decision has to be made which is more important for the process: less dissolved reaction products and less recycling of chemicals in the reactor, or, more recycling and more dissolved reaction products present. One can imagine situations where the recycling approach would be very attractive. This is true, for instance, in the case of recycling some special valuable chemicals back to the process. Such chemicals could be expensive bleaching agents (caustic soda, hydrogen peroxide, peracetic acid), enzymes and dissolved reaction activators (molybdate, polyoxometalates).

The model and chosen initial values had some limitations that certainly affect the actual numerical values of the results in comparison with a real process. Such limitations could be the accuracy of the displacement matrix, the assumption of washing efficiencies, amount and purity of wash water, decomposition of active chemicals in the filtrate tank, sorption, and diffusion phenomena. However, the calculated results agreed fairly well with the earlier results obtained for fractional washing, although the latter concentrated mainly on washing efficiency in earlier stages of wood pulp fibre processing (brown stock washing, post-oxygen washing). A clear increase in washing efficiency of between 10 and 30% has been reported depending on the fractional filtrate concept used in the process [4,6,8].

A sensitivity analysis confirmed the potential of the two different strategies with fractional filtrate configurations (Table 2). The results from Configurations 5 and 7 differed clearly from the reference (Configuration 1) in a wide range of initial values. Higher displacement efficiency in the second filter washer and lower chemical consumption in the bleaching reactor increased the benefits of fractional filtrate configurations.

The idea of fractional filtrate configurations is based on universally applicable knowledge of chemical engineering. In theory, it is simply a question of mixing or not mixing different liquors before using them in other positions of the process. Thus general conclusions are easy to draw from the results and they can easily be accepted as fairly objective. There are no theoretical limitations to limit the applications of this idea in connection to wood pulp fibre processing. The idea of fractional filtrate configuration should be of interest in other branches of industry, such as chemical and mining industries. The fractional filtrate concept seems to be a simple and effective way to improve liquor-based process behaviour.

5. Conclusions

The simulation results clearly demonstrate that responses in connection to bleaching of wood pulp fibres can be modified by utilising specific fractional filtrate configurations. This was especially evident for increasing the washing efficiency of dissolved reaction products, or improving the recyclability of active residual chemicals back to the process. However, these two improvements are contradictory. Both of these improvements find practical applications in different stages of wood pulp fibre processing. The choice depends on process details such as the harmfulness of the dissolved reaction products and the value of the residual chemicals.

These results encourage the creation of process machinery and configurations where different filtrate fractions are formed. There are no theoretical limitations that would prevent the concept of fractional filtrate configuration from being utilised in branches of the chemical and mining industries.

Appendix A

The displacement operation in the first filter washer was modelled using a Nordén wash model with a conventional Nordén number of 4.0 [1]. The displacement operation in the second filter washer was performed using a (3×6) matrix of partial ideal mixing stages. Pulp fed to the second filter washer was divided horizontally into three equal-sized pulp fractions (i.e. first column). Each fraction was at a constant washing consistency. The wash water was divided into six portions of equal size, from which the first portion was introduced as wash water to the top fraction of the first column. After ideal mixing of the pulp fraction and the first portion of wash water, the filtrate moved vertically as a new wash liquor to the next fraction of the same column (from 1 to 2, and 2 to 3), and the pulp fraction moved horizontally to the next column of the matrix (from 1 to 2, 2 to 3, and so on). Thus, in total eighteen partial ideal mixing stages were used to complete the calculation procedure. This type of approach was required in order to maintain the concentration profile in the fibre mat during displacement and to approximate two different filtrates out of the washer [4,6,8]. Each ideal mixing stage had a theoretical washing efficiency E_k of 1.15 [1,2,14]. The liquor discharged from the bottom of the first three columns of the matrix was mixed together and expressed as the "filtrate from the first displacement zone" (Table 1). Similarly, the liquor discharged from the columns 4 to 6 was expressed as the "filtrate from the second displacement zone".

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