Optimization of Steam Economy in Multiple Effect Evaporator

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Abstract

Chemical recovery is an important operation in pulp and paper industry from the economic point of view. One of the main steps in the recovery of alkaline pulping chemicals is the concentration of black liquor to a higher solids content by evaporation. This paper deals with the complete material and energy balance which was performed in a Microsoft Excel worksheet to calculate the Steam economy for multiple effect evaporator (five effect). Also suggestions have been made to improve the steam economy by increasing one effect from existing five effect in a multiple effect evaporator, increasing liquor temperature, decreasing steam pressure.

INTRODUCTION

Black liquor concentration, expressed as percent solids, is generally measured by drying a liquid sample under specified conditions. The terms "weak black liquor" describes the lower concentration (usually 8-20% solids) liquor from brown stock washing; "strong black liquor" refers to high concentration liquor (usually 50% solids) from the multiple effects evaporators; "heavy black liquor" refers to the liquor fired into the furnace.

In most plants direct contact evaporators have been used to raise the concentration of black liquor (usually 60% and above) coming from multiple effect evaporators.

The additional evaporation can be achieved either by simply© extending the operation of the multiple effect evaporation unit to the higher solids level or by adding a concentrator which uses a separate steam flow or flue gas flow. The advantages of concentrating the liquor is that its net heating value is increased as more steam can be generated in the boiler. When the well concentrated black liquor is sprayed into a recovery furnace, it will ignite and generate more steam. The great disadvantage is the scale formation which can be removed by drilling or by mechanical means.

Mass and energy balance

The Table below shows the complete material and energy balance in Microsoft Excel which is more useful to calculate the steam economy of the evaporator for various readings. By entering only the existing data we will get a detailed report of material and energy balance. There will no need of doing material and energy balance each and every time. The steam economy obtained for the existing five effect in a multiple effect evaporator is 4.37 Table 1.

Suggestions for improving

The steam economy

Number of effects

The dominant variable that influences the steam economy is the number of effects. The number of effects is directly proportional to the steam economy. By increasing one effect from the existing five effect it will increase the steam economy.

Liquor feed temperature

The liquor feed temperature is directly proportional to the steam economy. By increasing the liquor feed temperature will increase the steam economy.

Steam pressure

Decreasing the steam pressure in the first effect will increase the steam economy. This is primarily due to the higher latent heat of steam at lower pressure and partly by the lower temperature levels throughout the evaporator.

Liquor and condensate flash

Flash steam from heavy liquor and from contaminated is beneficial to steam economy. Steam condensate

	A	B	C
1.	**Multiple effect evaporator mass and energy balance**		
2.	**Evaporator effect**	**Units**	**FC**
3.	Pre-heater		
4.	Steam flow	tonnes	
5.	Steam temperature	°C	
6.	Liquor inlet temperature	°C	
7.	liquor flow	tonnes	
8.	Liquor outlet temperature	°C	
9.	Liquor concentration	%	
10.	**Evaporator in**		
11.	Steam flow (Primary flash)	Tonnes	
12.	Steam flow (Secondary flash)	Tonnes	
13.	Stema flow (Total)	Tonnes	Enter Value
14.	Steam temperature	°C	Enter Value
15.	Latent heat	kJ/kg.K	=2270-(CI4-95)*2.65
16.	Liquor flow	Tonnes	D = 25
17.	Liquor temperature	°C	D = 26
18.	Liquor concentration	%	D = 27
19.	**Evaporator out**		
20.	Vapour flow (Sensible heat)	Tonnes	= MIN(0,(C17-C26)*4.2*(C 16 + $H$19* 0.5) /C 15)
21.	Vapour flow (flash)	Tonnes	= MAX(C,(C 17-C26)*4.2* (C 16+$H$19 *0.5) /C24)
22.	Vapour flow (total)	Tonnes	= (C13+C20)*C15/C24)+C21
23.	Vapour temperature	°C	Enter value
24.	Latent heat	kJ/kg.K	= 2270-(C23-95)*2.65
25.	Liquor flow	Tonnes	= (C16-C22)
26.	Liquor temperature	°C	Enter value
27.	Liquor concentration	%	= $H$19/(C25+$H$19)
28.	Condensate flow (Primary)	Tonnes	C = 13
29.	Condensate flow (Secondary)	Tonnes	
30.	Condensate temperature	°C	C = 14
31.	**Steam Economy**		

flashing would also increase the steam economy of theevaporator.

Liquor flow sequence

The liquor flow sequence within the evaporator system can markedly influence the steam economy. It is common practice to introduce the feed liquor into the high vacuum effects and pump the liquor in a straight backward flow to the first or steam effect. The feed liquor is preferably introduced at the effect nearest the liquor temperature to minimize liquor preheating or flashing. Many LTV evaporators, therefore, use variations of the backward flow to increase steam economy. Many liquor flow sequences are possible in LTV trains that feature integral liquor preheaters or after heaters.

Evaporator scaling

When an evaporator becomes scaled, the steam pressure should be increased to main evaporator capacity, which will be decrease the steam economy.

	D	E
1.		
2.	1	2
3.		
4.	= (D8-D6)*4.2* (D7+$H$19*0.5)D24	= (E8-E6)*4.2* (E7+$H$19*0.5)/E24
5.	= D 23	= E 23
6.	= E 26	= F 26
7.	= E 25	= F 25
8.	Enter value	Enter value
9.	= E 27	= F 27
10.		
11.		
12.		=((D30-E14)*4.2*(C28+D28)/(E15))
13.	Enter Value	
14.	Enter Value	=(C22+D22+E11+E12+D4)
15.	=2270-(D14-95)*2.65	=D23
16.	= D7	=2270-(E14-95)*2.65
17.	= D8	=E7
18.	= D9	=E8
19.		=E9
20.	=MIN(0,(D17-D26)*4.2*(D16+$H$19*0.5)/D15)	=MIN(0,(E 17- E26)*4.2*(E 16+$H$19*0.5)/E 15)
21.	=MAX(0,(D17-D26)*4.2*(D16+$H$19*0.5)/D24)	=MAX(0,(E 17-E26)*4.2*(E16+$H$19*0.5)/E24)
22.	=((D13+D20)*D15/D24)+D21	=((E 13+E20)*E 15/E24)+E21
23.	ENTERVALUE	Enter value
24.	=2270-(D23-95)*2.65	=2270-(E23-95)*2.65
25.	=(D16-D22)	=(E16-E22)
26.	ENTER VALUE	Enter value
27.	=$H$19/(D25+$H$19)	=H 19/(E25+H 19)
28.	=D13	=(C28+D28-E11)
29.		=(D29-E12)+E13+D4
30.	=D14	=E14
31.		

To increase it, scaling should be controlled.

RESULTS AND DISCUSSION

By installing one more effect to the existing multiple effect evaporator (five effect to six effect),there is an appreciable increase in steam economy (4.37 to 5.42), evaporation rate (60.7 tons to 65.6 tons) and final concentration of black liquor from 42% to 49%; Steam economy (5.42 to 5.44 of 5.46), evaporation rate (65.6 tons to 65.9 tons and 66.0 tons) and final concentration of black liquor (49% to 50%) can be improved by increasing the liquor feed temperature from 73°C to 75°C and 77°C (Table 2, 3 & 4).

Steam economy (5.46 to 5.60), evaporation rate (66.0 tons to 67.8 tons) and final concentration of black liquor (50% to 53%) can also be improved by decreasing the steam pressure which lowers steam temperature from 151°C to 148°C (Table 4 & 5). Steam economy can also be increased by reducing scaling problems, steam condensate flashing and variations in liquor flow sequence. Cost saved by increasing one effect from existing multiple effect

	F	G
1.		5-4-3-2-1-FC
2.	3	4
3.		
4.	= (F8-F6)*4.2* (F7+$H$19*0.5)/F24	= (G8-G6)*4.2* (G7+$H$19*0.5)/G24
5.	= F 23	= G 23
6.	= G 26	= H 26
7.	= G 25	= H 25
8.	Enter value	Enter value
9.	= E 27	= H 27
10.		
11.	= (E30-F14)*4.2* (E28/(F15)	
12.	= (E30-F14)*4.2* (E29/(F15)	= ((F30-G14)*4.2*F28/(G15)
13.	= (E22+F11+F12-E4)	= ((F30-G14)*4.2*F29/(G15)
14.	= E 23	= (F22+G11+G12+F4)
15.	=2270-(F14-95)*2.65	= F 23
16.	= F7	=2270-(G14-95)*2.65
17.	= F8	= G 7
18.	= F9	= G 8
19.		= G 9
20.	=MIN(0,(F17-F26)*4.2*(F16+$H$19*0.5)/F15)	=MIN(0,(G 17- G26)*4.2*(G 16+$H$19*0.5)/G15)
21.	=MAX(0,(F17-F26)*4.2*(F16+$H$19*0.5)/F24)	=MAX(0,(G 17-G26)*4.2*(G16+$H$19*0.5)/G24)
22.	=(F13+F20)*F15/F24)+F21	=((G 13+G20)*G 15/G24)+G21
23.	ENTERVALUE	Enter value
24.	=2270-(F23-95)*2.65	=2270-(G23-95)*2.65
25.	=(F16-F22)	=(G16-G22)
26.	ENTER VALUE	Enter value
27.	=$H$19/(F25+$H$19)	=H 19/(G25+H 19)
28.	=(E28-F11)	=(F28-G11)
29.	=(E29-F12)=F13=E4	=(F29-G12)+G13+F4
30.	=F14	=G14
31.		

evaporator(five effect) = Rs. 53, 61, 120/year

CONCLUSION

Steam economy can be increased by increasing one effect from existing five-effect evaporator to six-effect evaporator. Increasing liquor feed temperature.(from 73°C to 75 °C & 77 °C). Decreasing steam pressure (i.e.) steam temperature.(from 151°C to 148°C). Condensate flashing. Variations in liquor flow sequence. Cost saved by increasing one effect from existing multiple effect evaporator(five effect)is Rs.53,61 ,120/year (cost of steam, 1 ton =Rs. 340).

	H	I
1.		
2.	5	6
3.		
4.	-	
5.	-	
6.	-	
7.	-	
8.	-	
9.	-	
10.		
11.	= (G30-H14)*4.2* (G28/(H15)	
12.	= (G30-G14)*4.2* (G29/(G15)	
13.	= (G22+H11+H12-G4)	
14.	= G 23	
15.	=2270-(H14-95)*2.65	
16.	ENTER VALUE	
17.	ENTER VALUE	
18.	ENTER VALUE	
19.	= H16*H18/(1-H18)	
20.	=MIN(0,(H17-H26)*4.2*(H16+$H$19*0.5)/H15)	
21.	=MAX(0,(H17-H26)*4.2*(H16+$H$19*0.5)/H24)	= SUM (C22:H22)
22.	=(H13+H20)*H15/H24)+H21	
23.	ENTER VALUE	
24.	=2270-(H23-95)*2.65	
25.	=(H16-H22)	
26.	ENTER VALUE	
27.	=$H$19/(H25+$H$19)	
28.	=(G28-H11)	
29.	=(G29-H12)=H13=G4	
30.	=F14	
31.		=SUM(C22:H22)/(C13+D13)

REFERENCES

1. MacDonald RG., and Franklin J.N., "The Pulping of Wood", 2nd Edition, Volume I, Page: 315-345, Tappi Press, (1965).
2. GW.Hough, "Chemical Recovery)' in the Alkaline Pulping Processes", Page: 81-103, Tappi Press (1985).
3. Swartz J.N., Muhonen lM., Lamarche LJ, Hambaugh P.C., Richter F.H., "Pulp and Paper' Manufacture", Volume I: The pulping of Wood; Chapter 8, Alkaline

Table 1 : MULTIPLE EFFECT EV APORA TOR MASS AND ENERGY BALANCE 5-4-3-2-1-FC

A	B	C	D	E	F	G	H	I
1 Evaporator effect	Units	FC	1	2	3	°4	5	6
2 PRE-HEATER								
3 Steam flow	tons		0.7	0.5	0.6	0.7	-	
4- Steam temperature	deg.C		131	110	95	81	-	
5 Liqour inlet temperature	deg.C		112	96	81	66	-	
7 Liquor flow (water)	tons		32	44	56	67	-	
8. Liquor outlet temperature	deg.C		121	101	86	71	-	
9 Liqour concentration	%		29%	22%	19%	16%	-	
10 EVAPORATOR IN								
11 Steam flow (pri. flash)	tons				0.5	0.5	0.4	0.3
12 Steam flow (sec. flash)	tons					0.6	0.8	1.0
13 Steam flow (total)	tons	3.4	10.5	13.8	13.0	12.2	11.3	
14 Steam temperature	deg.C	151	151	131	110	95	81	
15 Latent heat	kJ/kg.K	2122	2122	2175	2230	2270	2307	
16 Liquor flow (water)	tons	23	32	44	56	67	79	
17 Liqour temperature	deg.C	133	121	101	86	71	73	
18 Liquor concentration	%	36%	29%	22%	19%	16%	14%	
19 EVAPORATOR OUT							12.8	
20 Vapour flow (sens.ht)	tons	0.0	-0.9	-1.1	-1.2	-1.4	0.0	
21 Vapour flow (flash)	tons	1.3	0.0	0.0	0.0	0.0	1.1	
22 Vapour flow (total)	tons	4.5	9.4	12.4	11.6	10.6	12.2	60.7
23 Vapour temperature	deg.C	110	131	110	95	81	66	
24 Latent heat	kJ/kg.K	2230	2175	2230	2270	2307	2347	
25 Liquor flow (water)	tons	18	23	32	44	56	67	
26 Liquor temperature	deg.C	109	133	112	96	81	66	
27 Liquor concentration	%	42%	36%	29%	22%	19%	16%	
28 Condensate flow (pri)	tons	3.4	10.5	13.4	12.8	12.5	12.2	
29 Condensate flow (sec)	tons			14.4	27.3	39.3	50.3	
30 Condensate temperature	deg.C	151	151	131	110	95	81	
31 STEAM ECONOMY								4.37

Table 2 : MULTIPLE EFFECT EVAPORATOR MASS AND ENERGY BALANCE 5-4-3-2-1-FC

A	B	C	D	E	F	G	H	I	J
2 Evaporator effect	Units	FC	I	2	3	4	5	6	7
3 PRE-HEATER									
4 Steam flow	tons		0.4	0.8	1.0	1.2	0.7	-	
5 Steam temperature	deg.C		130	115	100	85	70	-	
6 Liqour inlet temperature	deg.C		113	100	85	70	60	-	
7 Liquor flow	tons		25	37	48	58	67	-	
8 Liquor outlet temperature	deg.C		120	110	95	80	65	-	
9 Liqour concentration	%		34%	26%	21%	18%	16%	-	
10 EVAPORATOR IN									
11 Steam flow (primary flash)	tons			0.5	0.3	0.3	0.3	0.3	
12 Steam flow (secondary flash)	tons				004	0.7	1.0	1.2	
13 Steam flow (total)	tons	2.9	9.2	12.1	11.5	10.7	10.1	10.1	
14 Steam temperature	deg.C	150	150	130	115	100	85	70	
15 Latent heat	kJ/kg.K	2125	2125	2178	2217	2257	2297	2337	
16 Liquor flow	tons	17	25	37	48	58	67	79	
17 Liqour temperature	deg.C	127	120	110	95	80	65	73	
18 Liquor concentration	%	43%	34%	26%	21%	18%	16%	14%	
19 EVAPORATOR OUT								12.9	
20 Vapour flow (sensible heat)	tons	0.0	-004	-0.3	-0.5	-0.6	-0.7	0.0	
21 Vapour flow (flash)	tons	0.7	0.0	0.0	0.0	0.0	0.0	2.0	
22 Vapour flow (total)	tons	3.5	8.5	11.6	10.8	10.0	9.2	12.0	65.6
23 Vapour temperature	deg.C	115	130	115	100	85	70	60	
24 Latent heat	kJlkg.K	2217	2178	2217	2257	2297	2337	2363	
25 Liquor flow	tons	13	17	25	37	48	58	67	
26 Liquor temperature	deg.C	111	127	113	100	85	70	60	
27 Liquor concentration	%	49%	43%	34%	26%	21%	18%	16%	
28 Condensate flow (primary)	tons	2.9	9.2	11.6	11.3	11.0	10.7	IO.4	
29 Condensate flow (secondary)	tons			12.5	24.4	35.5	45.8	55.3	
30 Condensate temperature	deg.C	150	150	130	115	100	85	70	
31 STEAM ECONOMY									5.42

TABLE 3 : MULTIPLE EFFECT EVAPORATOR STREET MASS AND ENERGY BALANCE

A	B	C	D	E	F	G	H	I	J
2 **Evaporator effect**	**Units**	**FC**	**I**	**2**	**3**	**4**	**5**	**6**	**7**
3 **PRE-HEA TER**									
4 Steam flow	tons		0.4	0.8	0.9	1.2	0.4	-	
5 Steam temperature	deg.C		130	115	100	85	70	-	
6 Liqour inlet temperature	deg.C		113	100	86	70	62	-	
7 Liquor flow	tons		25	37	48	58	67	-	
8 Liquor outlet temperature	deg.C		120	110	95	80	65	-	
9 Liqour concentration	%		34%	26%	21%	18%	16%	-	
10 EVAPORATOR IN									
11 Steam flow (primary flash)	tons			0.5	0.3	0.3	0.3	0.3	
12 Steam flow (secondary flash)	tons				0.4	0.7	1.0	1.2	
13 Steam flow (total)	tons	2.9	9.2	12.1	11.5	10.9	10.1	10.4	
14 Steam temperature	deg.C	150	150	130	115	100	85	70	
15 Latent heat	kJ/kg.K	2125	2125	2178	2217	2257	2297	2337	
16 Liquor flow	tons	17	25	37	48	58	67	79	
17 Liqour temperature	deg.C	127	120	110	95	80	65	75	
18 Liquor concentration	%	44%	34%	26%	21%	18%	16%	14%	
19 EVAPORATOR OUT								12.9	
20 Vapour flow (sensible heat)	tons	0.0	-0.4	-0.3	-0.5	-0.7	-0.7	0.0	
21 Vapour flow (flash)	tons	0.7	0.0	0.0	0.0	0.0	0.0	2.0	
22 Vapour flow (total)	tons	3.5	8.5	11.6	10.8	10.0	9.2	12.2	65.9
23 Vapour temperature	deg.C	115	130	115	100	85	70	60	
24 Latent heat	kJ/kg.K	2217	2178	2217	2257	2297	2337	2363	
25 Liquor flow	tons	13	17	25	37	48	58	67	
26 Liquor temperature	deg.C	111	127	113	100	86	70	62	
27 Liquor concentration	%	49%	44%	34%	26%	21%	18%	16%	
28 Condensate flow (primary)	tons	2.9	9.2	11.6	11.3	11.0	10.7	10.4	
29 Condensate flow (secondary)	tons			12.5	24.4	35.5	45.8	55.3	
30 Condensate temperature	deg.C	150	150	130	115	100	85	70	
31 STEAM ECONOMY									5.44

TABLE 4 : MULTIPLE EFFECT EVAPORATOR MASS AND ENERGY BALANCE 6-5-4-3-2-1-FC

	A	B	C	D	E	F	G	H	I	J
2	**Evaporator effect**	**Units**	**FC**	**I**	**2**	**3**	**4**	**5**	**6**	**7**
3	**PRE-HEATER**									
4	Steam flow	tons		0.4	0.8	0.9	0.8	0.0	-	
5	Steam temperature	deg.C		130	115	100	85	70	-	
6	Liqour inlet temperature	deg.C		113	100	86	73	65	-	
7	Liquor flow	tons		25	37	47	57	67	-	
8	Liquor outlet temperature	deg.C		120	110	95	80	65	-	
9	Liqour concentration	%		34%	26%	21%	18%	16%	-	
10	**EVAPORA TOR IN**									
11	Steam flow (primary flash)	tons			0.5	0.3	0.3	0.3	0.3	
12	Steam flow (secondary flash)	tons				0.4	0.7	1.0	1.2	
13	Steam flow (total)	tons	2.9	9.2	12.1	11.5	10.9	10.4	10.7	
14	Steam temperature	deg.C	150	150	130	115	100	85	70	
15	Latent heat	kJ/kg.K	2125	2125	2178	2217	2257	2297	2337	
16	Liquor flow	tons	16	25	37	47	57	67	79	
17	Liqour temperature	deg.C	127	120	110	95	80	65	77	
18	Liquor concentration	%	44%	34%	26%	21%	18%	16%	14%	
19	**EVAPORATOR OUT**								12.9	
20	Vapour flow (sensible heat)	tons	0.0	-0.4	-0.2	-0.5	-0.7	-1.1	0.0	
21	Vapour flow (flash)	tons	0.7	0.0	0.0	0.0	0.0	0.0	1.8	
22	Vapour flow (total)	tons	3.5	8.6	11.6	10.8	10.0	9.2	12.4	66.0
23	Vapour temperature	deg.C	115	130	115	100	85	70	60	
24	Latent heat	kJ/kg.K	2217	2178	2217	2257	2297	2337	2363	
25	Liquor flow	tons	13	16	25	37	47	57	67	
26	Liquor temperature	deg.C	III	127	113	100	86	73	65	
27	Liquor concentration	%	50%	44%	34%	26%	21%	18%	16%	
28	Condensate flow (primary)	tons	2.9	9.2	11.6	11.3	11.0	10.7	10.4	
29	Condensate flow (secondary)	tons			12.5	24.4	35.5	45.8	55.3	
30	Condensate temperature	deg.C	150	150	130	115	100	85	70	
31	**STEAM ECONOMY**									5.46

Pulping, Tappi Press (1980).

4. Newell Stephenson J., "Pulp and Paper Manufacture", Volume II: Preparation and Treatment of Wood Pulp; Chapter 6: Equipment and Operation, Tappi Press (1985).

5 Thomas M. Grace, "Pulp and Paper' Manufacture", Volume. V: Alkaline Pulping; Chapter 20: Preparation Of White Liquor, The Joint Textbook Committee of the Paper Industry (1989).

6. Kinzer K, "Symposium on Recovery)' of Pulping Chemicals", Page:279 (1968).

7. Venkatesh, V. and Nuygen, XN., "Evaporation and

TABLE 5 : MULTIPLE EFFECT EVAPORATOR MASS AND ENERGY BALANCE 6-5-4-3-2-1-FC

A	B	C	D	E	F	G	H	I	J
2 **Evaporator effect**	**Units**	**FC**	**I**	**2**	**3**	**4**	**5**	**6**	**7**
3 **PRE-HEATER**									
4 Steam flow	tons		0.4	0.9	I.I	1.6	0.6	-	
5 Steam temperature	deg.C		132	116	100	83	68	-	
6 Liqour inlet temperature	dcg.C		113	99	84	68	60	-	
7 Liquor flow	tons		23	35	46	56	66	-	
8 Liquor outlet temperature	deg.C		120	110	95	82	65	-	
9 Liqour concentration	%		36%	27%	22%	19%	16%	-	
10 EVAPORATOR IN									
11 Steam flow (primary flash)	tons			0.4	0.3	0.3	0.4	0.3	
12 Steam flow (secondary flash)	tons				0.4	0.6	1.2	1.3	
13 Steam flow (total)	tons	2.9	9.2	12.1	11.5	10.8	10.3	10.7	
14 Steam temperature	deg.C	148	148	129	114	100	82	66	
15 Latent heat	kJl/g.K	2130	2130	2180	2220	2257	2305	2347	
16 Liquor flow	tons	15	23	35	46	56	66	79	
17 Liqour temperature	deg.C	127	120	110	95	82	65	77	
18 Liquor concentration	%	47%	36%	27%	22%	19%	16%	14%	
19 EVAPORATOR OUT								12.9	
20 Vapour flow (sensible heat)	tons	0.0	-0.4	-0.2	-0.4	-0.2	-0.4	0.0	
21 Vapour flow (flash)	tons	0.6	0.0	0.0	0.0	0.0	0.0	2.6	
22 Vapour flow (total)	tons	3.4	8.6	11.7	10.9	10.3	9.7	13.2	67.8
23 Vapour temperature	deg.C	113	132	116	100	83	68	60	
24 Latent heat	kJ/kg.K	2223	2172	2215	2257	2302	2342	2363	
25 Liquor flow	tons	II	15	23	35	46	56	66	
26 Liquor temperature	deg.C	III	127	113	99	84	68	60	
27 Liquor concentration	%	53%	47%	36%	27%	22%	19%	16%	
28 Condensate flow (primary)	tons	2.9	9.2	11.7	11.3	11.0	10.7	10.4	
29 Condensate flow (secondary)	tons			12.5	24.5	35.7	46.3	56.4	
30 Condensate temperature	deg.C	148	148	129	114	100	82	66	
31 STEAM ECONOMY									5.60

Concentration of Black Liquor" Page: 124-156 Tappi Press (1985).

8. Grace,T.M., "A Survey of Evaporator Scaling in the Alkaline Pulp Industry" (1985).

9. Raymond, D.R., Rosen, A. and Grace,TM.,1983,"Comparison of Scaling characteristics of soda AQ and Kraft Black Liquor" Summer national AIChE Meeting.