A Comparative Process Analysis Of Energy Balance For Conventional Batch Digester And Superbatch™ Digester

RajaSankar.R, Venkoba Rao.G

ABSTRACT

The comparative analyses of energy balance calculation over conventional batch digester and super batch digester was presented. The energy balance calculation for batch digester helps in understanding of the thermodynamics of a blow heat systems' avoids errors in calculating the amount of energy going to blow heat recovery system and prevents vapour release and energy loss to atmosphere. The comparative analyses of energy balance calculation shows for a batch digester of about a volume of 80 m^3 requires about 4.27×10^9 joules/ton of pulp produced (without blow heat recovery) and superbatch digester of about a volume of 200 m^3 requires only about 1.9×10^9 joules/ton of pulp produced. Even when blow heat recovery calculation was used the superbatch value is only about 70 to 80% the value of conventional batch digester. The energy balance calculation also provides the information about material balance for washers and evaporator, total dissolved solids produced per ton of pulp produced, % liquor solids, blow tank (discharge tank) pulp consistency etc, was presented.

Key words: energy balance, conventional batch digester, superbatch digester.

1. INTRODUCTION

Energy is the main concern of today's industries. Energy efficient process takes over the earlier energy consuming conventional process. Paper industries today switch over to other energy efficient process from Europe and other countries viz.,superbatch™,RDH, lo-solids™ pulping etc.These process may now reduce the energy required for pulping and are boon to the pulp and paper industries.[1][2][3][4]

In this paper a comparative calculation over energy balance and material balance for conventional batch cooking and superbatch cooking process is presented. The energy cycle is open loop in case of conventional batch cooking and closed loop in case of superbatch cooking. Hence the superbatch cooking is considered as the energy efficient cooking process. Blow heat recovery systems are useful in case of conventional cooking process, since they provide the hot water at 90°C-100°C for brown stock washers, bleach plants etc.[5]

2. SYSTEM ANALYSIS

To make a process and thermodynamic analysis of the digester, consider a 80 m^3 conventional batch digester and a 200 m^3 superbatch digester. Table-1

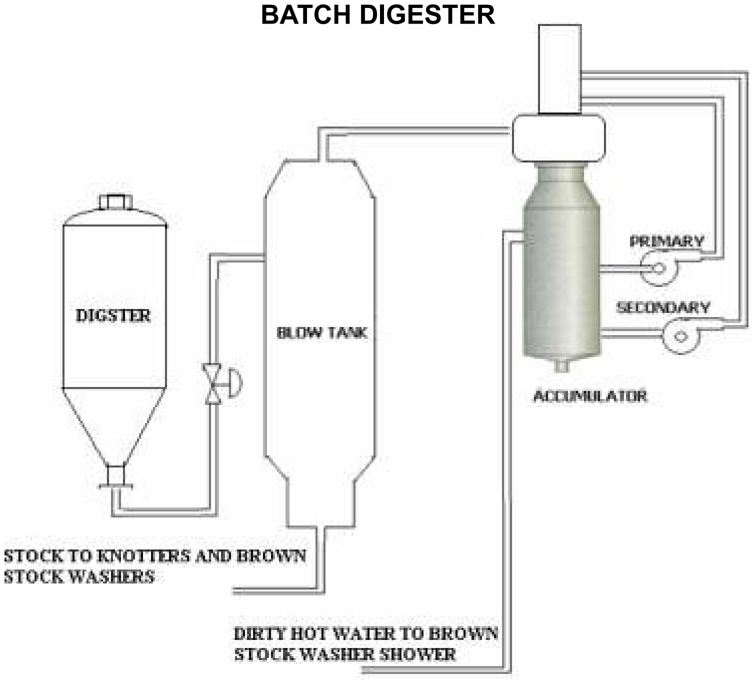
TABLE - 1

TYPICAL PRODUCTION DATA FOR CONVENTIONAL BATCH DIGESTER AND SUPERBATCH DIGESTER

slno	PARAMETER	CONVENTIONAL BATCH DIGESTER	SUPERBATCH DIGESTER
1.	Digester yield, tons/digester	9.66	25.3
2.	Chips charged , tons/digester	30.00	55.00
3.	Yield %	46%	46%
	WOOD PROPERTIES		
4.	Moisture%	30%	30%
5.	Temperature	30	30
6.	Specific heat, J/kg	2104.9	2104.9
	FIRST STAGE FILTRATE BLACK LIQUOR		
7.	Solids%	12%	16%
8.	Dry solids specific heat, J/kg	2009.6	2009.6
9.	Temperature	60	80
	WHITE LIQUOR		
10.	Active alkali, kg/m^3	81	82
11.	Total solids	1.40	1.40
12.	Specific gravity	1.0325	1.0325
13.	Temperature,	60	60
14.	Solids specific J/kg	2009.6	2009.6
	BLACK LIQUOR		
15.	Charged,m^3/digester	12	28.9
16.	Total solids %	14	18%
17.	Bulk density kg/liter	1.1041	1.1041
18.	Active alkali charged	15%	19%
19.	COOKING TEMPERATURE	165	162

Department of Chemical Technology, Bharathidasan University, Tiruchirapalli

FIGURE 1
BLOW HEAT RECOVERY SYSTEM FOR CONVENTIONAL BATCH DIGESTER



shows the typical production data for both digesters. The values given in the table.1 may vary from one mill to another. It is necessary for energy balance to calculate the pulp, lignin, wood chips fed into the digester, solids and water within black liquor and white liquor as given in Table.2. Information on heat losses due to heating digester shell, radiation loss, venting of gases, etc should be taken into account. Figure 1 shows the blow heat system for conventional batch digester.

Typical data's for energy balance should be suitably assigned matching their own mill conditions. The values assigned for the heat losses are taken as, heating the shell of digester as 150×10^6 joules/ton of pulp, Heating insulation of digester as 10.55×10^6 joules/ton of pulp. Radiation losses as 26.0×10^6 joules/ton of pulp. Relief gas flow rate is taken as 180 kg/ton of pulp.

TABLE 2
CALCULATON OF VARIOUS MATERIALS PRESENT IN THE DIGESTER

lno	PARAMETER	FORMULA	CONVENTIONAL BATCH DIGESTER	SUPERBATCH DIGESTER
1	Wood moisture (tons)	$\left(\frac{\%\ moisture}{100}\right)\times chips$	9.0	21.45
2	O.D wood (tons)	$\left(\frac{\%\ O.D\ wood}{100}\right)\times chips$	21.0	50.05
3	Pulp (tons)	yield tons of O.D wood	9.66	23.023
4	Lignin (tons)	tons of O.D wood –tons of pulp	11.34	27.027
5	Black liquor Charged (liters/digester)		12000	28900
6	Black liquor Mass (kg)		13249.2	31908.49
7	Black liquor solid mass (kg)	$\left(\frac{\%\ black\ liquor\ solid\ mass}{100}\right)\times mass\ of\ black\ liquor$	1589.904	5743.5282
8	Black liquor water mass(kg)		11659.3	26164.961
9	Active alkali charged (kg)	$\left(\frac{\%active\ alkali}{100}\right)\times O.D\ wood$	3150 .0	9509.5
10	White liquor charged (m^3)	$\frac{active\ alkali\ charged}{active\ alkali}$	38.89	100.00
11	White liquor mass (kg)		57283.58941	147296.45
12	White liquor solids charged (kg)		3889.0	10000.0
13	White liquor water charged (kg)		53394.54	137296.45

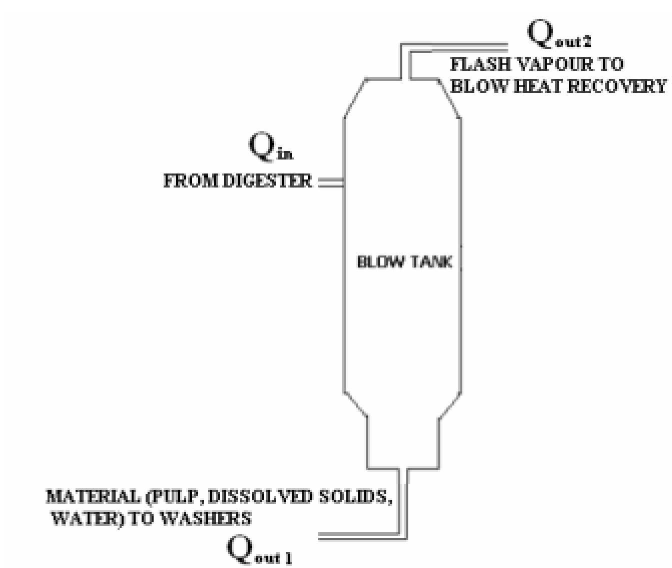
TABLE 3

HEAT REQUIREMENTS FOR THE DIGESTERS

slno	MATERIAL	CONVENTIONAL BATCH DIGESTER						SUPERBATCH DIGESTER					
		weight $\times 10^3$	specific heat $\times 10^3$	initial temp	final temp	diff. Temp	required $\times 10^3$	weight $\times 10^3$	specific heat $\times 10^3$	initial temp	final temp	diff. Temp	required $\times 10^3$
		Kg	Joules/kg °C	°C	°C	°C	Joules/digester	Kg	Joules/kg °C	°C	°C	°C	Joules/digester
1.	Pulp	9.66	2.10499	30	165	135	2.745	23.023	2.10499	80	162	82	3.9739
2.	Lignin	11.34	2.0096	30	165	135	3.0765	24.32	2.0096	80	162	82	4.0075
3.	Wood moisture	9.0	4.1867	30	165	135	5.0869	21.45	4.1867	80	162	82	7.36415
4.	White liquor solids	3.889	2.0096	80	165	85	0.664304	9.979	2.0096	140	162	22	0.441051
5.	White liquor water	53.39	4.1867	80	165	85	19.001	137.29	4.1867	140	162	22	12.645
6.	Black liquor solids	1.589	2.009	80	165	85	0.271581	5.7435	2.009	140	162	22	0.253851
7.	Black liquor water	11.65	4.1867	90	165	75	3.6611	26.164	4.1867	140	162	22	2.40989
8.	Digester shell	150 $\times 10^6$ j/ton $\times$9.66					1.449	150 $\times 10^6$ j/ton $\times$23.023					3.453
9.	Digester insulation	10.55 $\times 10^6$ j/ton $\times$9.66					0.11592	10.55 $\times 10^6$ j/ton $\times$23.023					0.241741
10.	Radiation	26 $\times 10^6$ j/ton $\times$9.66					0.241	26 $\times 10^6$ j/ton $\times$23.023					0.598598
11.	Relief	180 kg/ton $\times$9.66 tons $\times$2.7725 $\times 10^6$					4.8924	180 kg/ton $\times$23.023 tons $\times$2.7725 $\times 10^6$					11.034
						TOTAL	41.20621					TOTAL	46.422681

FIGURE 2

ENERGY BALANCE IN BLOW TANK (CONVENTIONAL BATCH DIGESTER)



3. HEAT REQUIREMENTS

In this energy balance calculation conventional batch digester and superbatch digester uses only indirect steaming for heating requirements. But superbatch digester originally uses direct steaming as only a small amount of steam is required to reach the cooking temperature of 162°C. This is because during hot liquor filling the hot black liquor at 140-155°C is pumped into the digester. Conventional batch digester uses shell and tube heat exchanger for transferring the steam temperature to the digester. Table-3 shows the heat requirements for both digester cooking systems.

4. END OF PROCESS REQUIREMENTS

In case of the conventional batch process the digester is at 165°C and approximately120 psig. During the process of blow which takes 15-20 minutes, the pulp is blown to the blow tank. The blow heat recovery system utilizes the flash vapour from the blow tank to generate the hot water at 90-100°C. In superbatch at end of cooking sequence, hot black liquor is displaced by displacement liquor. The hot black liquor displaced out is stored in hot black liquor tank for future cooking process. Then the pulp is discharged from the digester. Temperature of the pulp at displacement sequence was calculated.

5. ENERGY BALANCE

Energy balance is performed on the materials entering and leaving the digester and the blow tank as shown in fig 1 and 2.

5.1. CONVENTIONAL DIGESTER

Using 0 for a zero energy base, it is possible to calculate the energy

TABLE 4
HEAT AVAILABLE FOR VAPOURISATION IN CONVENTIONAL BATCH COOKING

Slno	MATERIAL	Kg/DIGESTER $\times 10^3$	SPECIFIC HEAT KJoules/kg °C	TEMP. °C	ENERGY joules $\times 10^9$
1.	Pulp	9.66	2.1499	65	1.3217
2.	Total dissolved solids	16.8189	2.0096	65	2.1969
3.	Total water	74.05387	4.1867	65	2.01527
			TOTAL		23.67135

TABLE 5
ENERGY WITH THE PULP TO WASHERS

Slno	MATERIAL	CONVENTIONAL BATCH DIGESTER				SUPERBATCH DIGESTER			
		kg/digester $\times 10^3$	Specific Heat KJoules/kg °C	Temp. °C	Energy Joules $\times 10^9$	kg/digester $\times 10^3$	Specific Heat KJoules/kg °C	Temp. °C	Energy Joules $\times 10^{12}$
1.	1. Pulp	9.66	2.10499	100	2.03342	23.023	2.1499	84.6550	3.91673
2.	2. Total dissolved solids	16.8189	2.0096	100	3.3799	33.56464	2.0096	84.6550	5.710
3.	3. Total water	63.565435	4.1867	100	2.6613	176.21436	4.1867	84.6550	62.45479
			TOTAL		32.0268		TOTAL		72.08525

entering the blow tank, (Q_{in}). The energy leaving the blow tank to the washers, ($Q_{out\,1}$) , and the energy in the flash vapour to the blow heat recovery ($Q_{out\,2}$) . Note the difference between the heat available for vaporization from the blow and the energy in the flash vapour to the blow heat vapour . The heat available for vaporization at 100 (h_f) is 2256.9 KJ/Kg K. when vapourizing one Kg of water in the blow tank, the saturated liquid contains 419.1 KJ/Kg K. of energy ,(h_f) , providing a total of 2676 KJ/Kg K.(2256.9+419.1) of energy, (h_g), in a Kg of vapour. Using the total joules available for vapourization, for the total joules going to the blow heat recovery rather than the total joules with the steam vapour introduces a 20% error in calculation. ($2.8067X10^{10}/23.67135X10^9=1.185$) The amount of water remaining in the blow tank is the difference between the total water in and the steam vapour. Here it is 63.56547Kg ($74.05387X10^3$-$10.4884X10^3$). Table.5 shows the energy leaving the blow tank to the washers. Obviously the total energy entering the blow tank must equal the energy leaving the blow tank to the washers and the energy in the flash vapour to the blow heat recovery. In this instance the total energy entering the blow tank is $56.71687X10^9$ joules, the energy leaving the blow tank to the washers is 32.0268 joules and the energy in the flash vapour to the blow heat recovery is $2.8067X10^{10}$ joules, rounding in the calculations causes the slight error in the balance. Table-4 shows the heat available for vaporization.

5.2. SUPERBATCH DIGESTER

For superbatch energy balance the total energy with the pulp and liquor inside the digester is calculated. Table.6 also shows the energy transfer during the displacement sequence. A typical value of 131.92×10^{12} joules is obtained for displacement sequence. The temperature of the pulp at the end of the displacement sequence is calculated as 84.6°C by the energy balance between pulp and liquor.Table.5 shows the energy inside the digester after cooking.

6. MATERIAL BALANCE

The material balance over digester provides the information about energy with the pulp to washers and evaporator calculation data.

6.1. CONVENTIONAL BATCH DIGESTER

Depending upon the steam flow to the digester and the yield and moisture content of the wood chips, will vary from $2.50X10^{10}$ to $2.8067X10^{10}$ joules/blow. This energy is in the $10.4884X10^3$ kg of steam vapour that flows into the blow heat recovery during the digester blow. If the blow lasts 15.0 minutes, then the average flow rates of blow vapours is 1320 Kg/minutes. The flow from the digester

APPENDIX – 1

CONVENTIONAL BATCH DIGESTER

MATERIAL BALANCE FOR WASHERS AND EVAPORATER DATA

Total material in the blow tank= Pulp+Total dissolved solids+Water

= 9.66+16.8189+63.565 = 90.0439 tons

% blow tank pulp consistency(without dilution)= $\frac{pulp \times 100}{total\ material} = \frac{9.66 \times 100}{90.0439}$ =10.728 %

% liquor solids= $\frac{total\ dissolved\ solids}{total\ dissolved\ soild + water} = \frac{16.8189}{16.8189+63.565} \times 100$ =20.923 %

Total dissolved solids produced per ton of pulp= $\frac{16.8189}{9.66}$ =1741.08737 $\frac{kg\ solids}{ton\ of\ pulp}$

Total energy required to produce per ton of pulp $\frac{41.20621 \times 10^9}{9.66}$

= 4.26565×10^9 joules/ton of pulp produced

APPENDIX – 2

SUPERBATCH DIGESTER

TEMPERATURE AFTER DISPLACEMENT SEQUENCE

Energy = $mc_p(\Delta T)$

ASSUMPTION:

After displacement sequence the pulp and the liquor attain the same temperature by energy transfer.

Energy balance in pulp: Energy with pulp =energy with liquor

Take as the temperature at the displacement, and proceed the calculation as follows

$$23.023 \times 10^6 \times 2.10499 \times (162 - x) = 33.56 \times 2.0096 \times 10^6 \times (x - 80) + 176.214 \times 4.18678 \times 10^6 \times (x - 80)$$

162- x =16.61 x -1329.2106

x =84.65508 °c , thus the Temperature of the Displacement sequence in calculated.

MATERIAL BALANCE FOR WASHERS AND EVAPORATER DATA

Total material in the blow tank =Pulp+Total dissolved solids+Water
=2 3.023+33.56464+176.21436 =232.802 tons

% blow tank pulp consistency (without dilution) = $\frac{pulp \times 100}{total\ material} = \frac{23.023 \times 100}{232.023}$ =9.8895 %

Energy required per ton of pulp produced = $\frac{46.0231015 \times 10^9}{23.023}$

=1.999 10^9 joules/ton of pulp produced.

TABLE 6
TOTAL ENERGY INSIDE THE DIGESTER AFTER COOKING

sl no	MATERIAL	CONVENTIONAL BATCH DIGESTER					SUPERBATCH DIGESTER				
			Kg/digester $\times 10^3$	Specific Heat KJoules/kg °C	Temp °C	Energy joules		Kg/digester $\times 10^3$	Specific Heat KJoules/kg °C	Temp. °C	Energy joules
1.	Pulp		9.66	2.10499	160	3.2534×10^9					
2.	Total dissolved solids		16.818	2.0096	160	5.4078×10^9		40.042	2.0096	162	6.512×10^{12}
	Lignin	11.34					24.32				
	White liquor solids	3.889					9.979				
	Black liquor solids	1.5899					5.7435				
3.	Total water		74.05387	4.1867	155	4.8056×10^9		184.9102	4.1867	162	1.254×10^{14}
	Wood moisture	9.0					21.45				
	White liquor water	53.39					137.29				
	Black liquor water	11.659					26.164				
				TOTAL		56.716×10^9			TOTAL		131.9×10^{12}

starts initially at a maximum instantaneous flow rate and then decays with time until the flow rate goes to zero, however one normally assumes that the maximum flow rate is 1.8 times the average flow rate. This provides a maximum flow rate of 2376 Kg/minute. This maximum flow rate is the basis of proper sizing of blow heat primary condenser. The Total energy required to produce per ton of pulp was calculated as 4.26565×10^9 joules/ton of pulp produced and the detailed calculation are shown in Appendix 1.

6.2. SUPERBATCH DIGESTER

In superbatch material balance should be concentrated on the displacement liquor. Hot black liquor contains high solids content than the displacement liquor. This is due to the displacement of the hot black liquor from the digester by using the displacement liquor. Most of the dissolved lignin are removed by the hot black liquor from the digester. The total material in the digester is 232.8 tons. Consistency of the pulp present in the digester is 10%. The temperature in the digester after displacement sequence was calculated as 84.6°C. The total Energy required per ton of pulp produced was calculated as $1.999X10^9$ joules/ton of pulp produced. The detailed calculation is shown in Appendix.2 .

CONCLUSION

From the energy balance calculation the energy required to produce per ton of pulp with conventional batch digester is 4.27×10^9 joules/ton of pulp produced and for superbatch digester is 1.99×10^9 joules/ton of pulp produced. The energy required for superbatch cooking is nearly half of the energy required for the conventional cooking.

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