PROCESS ANALYSIS OF A BATCH DIGESTER BLOW HEAT RECOVERY SYSTEM

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UNDERSTANDING THE THERMODYNAMICS OF A BLOW HEAT SYSTEM AVOIDS ERRORS IN CALCULATING THE AMOUNT OF ENERGY GOING TO BLOW HEAT RECOVERY AND PREVENTS VAPOR RELEASE AND ENERGY LOSS TO THE ATMOSPHERE.

MANY PULP MILLS HAVE INADEQUATE BLOW HEAT recovery systems indicated by vapor emission problems. The most visible sign of trouble is the release of unwanted vapor from the heat accumulator pressure relief valve shortly after a batch digester starts to blow. The unwanted vapor causes two problems—loss of energy and environmental pollution. To find solutions to these problems, one must have some basic knowledge about blow heat recovery systems.

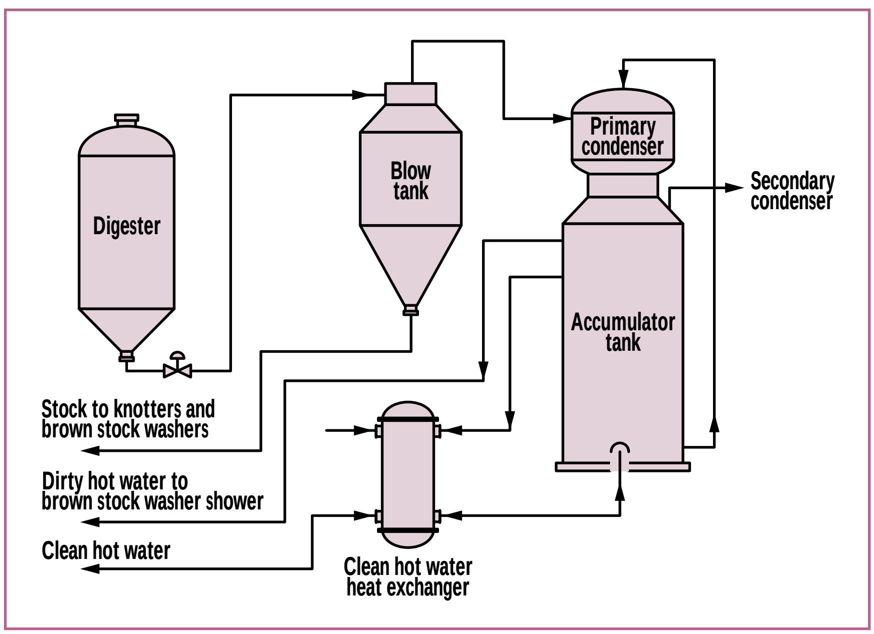
To explore the blow heat recovery system, I will perform a process balance around a batch digester and blow tank that will allow correct sizing of the blow heat recovery system. There will also be a complete thermodynamic analysis of the digester, blow tank, and heat recovery systems. Such an analysis is necessary for proper sizing of a blow heat system.

DESCRIPTION

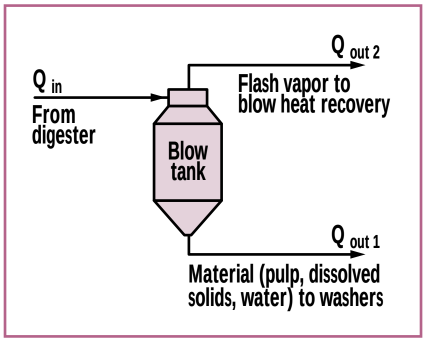
A blow heat recovery system has three primary functions:

- It condenses vapor from the blow tank.
- It stores the energy from blow heat vapor in the form of hot water contained in an accumulator tank.
- It provides a constant supply of energy in the form of hot water from the intermittent blow vapor.

Figure 1 is a diagram of a blow heat system. The primary condenser receives vapor from the blow tank and condenses it into water at 190–212°F. This hot water goes to the accumulator tank for storage and later use. The next step involves using the heat stored in the accumulator tank as follows:



1. Blow heat system



2. Energy diagram for the blow tank

Digester yield, ton/digester	18.41
Chips charged, lb/digester	154,400
Yield, %	50
Wood properties:	
Moisture, %	52.30
Temperature, °F	70
Specific heat	.33
First stage filtrate black liquor:	
Solids, %	15
Dry solids specific heat	.30
Temperature, °F	90
White liquor:	
Active alkali, lb/ft^3	6.00
Total solids, lb/gal	1.40
Specific gravity	1.16
Temperature, °F	140
Solids specific heat	.35
Black liquor:	
Charged, gal/digester	1304
Total solids, %	15
Bulk density, lb/gal	8.95
Active alkali charged:	
% on o.d. wood	17.60
Cooking temperature, °F	350

I. Typical production data

Wood moisture = [(% moisture)/100] x lb chips = 0.523 x 154,400 = 80,751 lb

O.d. wood = [(% o.d. wood)/100] x lb chips = 0.477 x 154,400 = 73,649 lb

Pulp = yield x lb o.d. wood = .50 x 73,649 = 36,825 lb (18.41 ton)

Lignin = lb o.d. wood - lb pulp = 73,649 - 36,825 = 36,825 lb

Weak black liquor volume = 1304 gal/digester

Black liquor mass = 1304 x 8.95 lb/gal = 11,671 lb/digester

Black liquor solids mass = [(% black liquor solids mass)/100] x mass = .15 x 11,671 = 1751 lb

Black liquor water mass = [(100 - 15)/100] x 11,671 = 9920 lb
Active alkali charged = [(%alkali)/100] x o.d. wood = .176 x 73,649 = 12,962 lb
White liquor charged, ft^3 = active alkali charged/active alkali = 12,962/6.0 = 2160 ft^3

White liquor charged, gal/digester = 2160 x 7.48 gal/ft^3 = 16,157 gal/digester

Total white liquor charged = white liquor charged x lb/gal x specific gravity = 16,157 x 8.34 x 1.16 = 156,309 lb

White liquor solids charged, lb/digester = 16,157 gal x 1.40 lb/gal = 22,620
White liquor water charged = 156,309 - 22,620 = 133,689 lb

II. Calculation of component parts in the digester

- Dirty hot water at approximately 190°F is pulled from the top of the accumulator, blended with other water, and used on the final brownstock washer stage as shower water. It is also possible to use the heat in this water for other purposes.
- In mills with bleach plants, additional water is removed from the top of the accumulator and put through one side of a heat exchanger to heat clean water for bleach plant shower use. The dirty water with heat removed in the heat exchanger returns to the bottom of the accumulator tank.

From this general description, one can see the importance of a blow heat system especially where it is a source of energy to process areas. The system provides recovered energy from the steam used to cook the digester.

SYSTEM ANALYSIS

To understand the blow heat recovery system, one must first examine the digester area and make a process and thermodynamic analysis of the digester contents. For the purposes of this analysis, let me assume a case using 6300 ft^3 direct steam digesters with a normal production rate of 500 o.d. tons per day obtained from the blow tank. Table I shows the typical production data taken from a mill producing a bleachable grade pulp that I will use for the digester balance.

Note that process data such as yield per digester, chips charged to the digester, wood moisture, percentage of black liquor solids, and white liquor strength will vary. One must obtain correct data for the particular application in question either from operation records or other sources.

It is necessary to break each material and substance fed into the digester into its component parts. One must calculate the pulp, lignin, and wood moisture contained within the wood chips. It is also necessary to know the solids and water contained within the black and white liquors. Table II details these calculations.

The additional information necessary for a digester energy balance includes heat losses due to heating the digester shell and insulation, radiation loss, and heat loss due to venting of digester noncondensable gases—relief gases.

The digester shell cools somewhat after blowing the digester. An energy value of 140,000 Btu/ton pulp is used to heat the shell back to the cooking temperature.

Material	Weight, lb/digester	Specific heat	Initial temp., °F	Final temp., °F	Differential Temp.	Required Btu/digester
Pulp	36,825	.33	70	350	280	3.403×10^6
Lignin	36,825	.30	70	350	280	3.093×10^6
Wood moisture	80,751	1.00	70	350	280	22.610×10^6
White liquor solids	22,620	.30	180	350	170	1.154×10^6
White liquor water	133,689	1.00	180	350	170	22.727×10^6
Black liquor solids	1,751	.30	190	350	160	$.084 \times 10^6$
Black liquor water	9,920	1.00	190	350	160	1.587×10^6
Digester shell	140,000 Btu/ton x 18.4 ton				2.576×10^6	
Digester insulation	10,000 Btu/ton x 18.4 ton				$.184 \times 10^6$	
Radiation	25,000 Btu/ton x 18.4 ton				$.460 \times 10^6$	
Relief	400 lb/ton x 18.4 ton x 1192 Btu/lb				8.773×10^6	
					Total heat, Btu/digester	$66,651 \times 10^6$

III. Digester energy balance heat showing input required

Steam properties:

h_g = 1208 Btu/lb

h_f = 339 Btu/lb

Btu/lb available = 1208 - 339
= 869 Btu/lb

Steam required:

lb/digester = (66.651×10^6 Btu/digester)/(869 Btu/lb)

lb/digester = 76,698 lb/digester

IV. Steam properties and requirement

The digester insulation also cools after the completion of a blow cycle. While the digester is cooking, approximately 10,000 Btu/ton pulp is necessary to heat the insulation back to its steady state temperature.

Radiation losses will vary depending on digester size, insulation used, etc. An estimate of radiation losses is 25,000 Btu/ton pulp. Relief gas flow rate varies widely from mill to mill. This article will use a relief gas flow rate of 400 lb per ton of pulp.

HEAT REQUIREMENTS

Table III lists the materials fed into a digester and tabulates the material weight, specific heat, initial temperature, final temperature, temperature difference, and Btu required to heat the substance to the 350°F cooking temperature. The table also includes values calculated for the energy required for the digester shell, digester insulation, and relief gases. The assumption is that direct steaming cooks the digester.

Direct steaming of a digester requires injecting live steam into the digester to heat the contents. The heat available from the steam will be the difference in enthalpy of the steam in the header and saturated condensate in the digester at 350°F. There is a further assumption that the steam is at 150 psig with 20°F superheat. Table IV shows steam properties from standard steam tables and a calculation of the steam requirement.

Note that many components listed in Table III such as the digester relief rate, total solids, and total water in the digester—wood moisture, black liquor makeup water, and white liquor water—can vary. All the components affect the total energy necessary to bring a digester to the proper cooking temperature.

END OF PROCESS REQUIREMENTS

Let me now examine the portion of the process at the end of the digester cooking period when the digester contents are discharged into the blow tank. The contents of the digester are at 350°F and approximately 120 psig. The operator opens the blow valve at the bottom of the digester to blow the digester contents through a blow line into the blow tank. Maximum pressure within the blow tank is approximately 2.5 psig with a corresponding temperature of 220°F. A period of 15–20 min is normally necessary for the digester to blow all its contents into the blow tank. Because of the lower temperature and pressure in the blow tank, a considerable amount of vapor flashes in the blow tank.

The recovery of the energy or heat within this flash steam is the primary purpose of the blow heat recovery system. A secondary and increasingly useful purpose of the blow heat system is to contain and convey the noncondensable gases released during the kraft cooking process.

ENERGY BALANCE

To understand the thermodynamics of events in a blow tank, I will perform an energy balance on the material entering and leaving the blow tank as Fig. 2 shows. The result of the energy balance around the blow tank will be the calculation of the amount of steam vapor flashed in the blow tank that passes to the blow heat recovery.

Using 32°F for a zero energy base, it is possible to calculate the energy entering the blow tank, Q_{in}, the energy

Material		lb/digester	Specific heat	T (320-32)	Btu
Pulp		36,825	.33	318	3.864 x 10^6
Total dissolved solids		61,200	.30	318	5.838 x 10^6
Lignin	36,825				
White liquor solids	22,620				
Black liquor solids	1,751				
Total water		293,698	1.0	318	93,396 x 10^6
Wood moisture	80,751				
White liquor water	133,689				
Black liquor water	9,920				
Steam:	76,698 - 7360 = 69,338				
				Total Btu	103.098 x 10^6

V.Total energy entering the blow tank

Material	lb/digester	Specific heat	*T (350 - 220)	Btu
Pulp	36,825	.33	130	1.580 x 10^6
Total dissolved solids	61,200	.30	130	2.387 x 10^6
Total water	293,698	1.00	130	38.181 x 10^6
			Total Btu available for vaporization	42,148 x 10^6

VI. Heat available for vaporization

leaving the blow tank to the washers, Q_{out1}, and the energy in the flash vapor to the blow heat recovery, Q_{out2}. Table V shows the energy entering the blow tank. Table VI gives the heat available for vaporization, and Table VII shows the calculation for the total Btu available for vaporization.

lb steam vapor = Total Btu/h_{fg} = 42,148 x 10^6/965.2 = 43,668 lb

h_{fg} is the enthalpy of vaporization for 200°F saturated steam.

Total Btu with steam vapor = lb x h_g = 43,668 x 1153.4 = 50.367 x 10^6 Btu

h_g is the enthalpy for 220°F for saturated steam.

Note that the total Btu with steam vapor is the Q_{out2}. This is the energy in the flash vapor to the blow heat recovery.

V11. Vaporization calculations

Note the difference between the heat available for vaporization from the blow and the energy in the flash vapor to the blow heat vapor. The heat available for vaporization at 220°F, h_{fg}, is 965.2 Btu/lb. When vaporizing one pound of water in the blow tank, the saturated liquid contains 188.13 Btu/lb of energy, h_f, providing a total of 1153.4 Btu/lb (188.13 + 965.2) of energy, h_g, in a pound of vapor. Using the total Btu available for vaporization for the total Btu going to the blow heat rather than the total Btu with the steam vapor introduces a 20% error into the calculation (50.367/42.148=1.20).

The amount of water remaining in the blow tank is the difference between the total water in and the steam vapor. Here it is 293,698-43,668 or 250,056 lb.

Table VIII 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 flash vapor to the blow heat recovery. In this instance the total energy entering the blow tank is 103.098 x 10^6 Btu. The energy leaving the blow tank to the washers is 52.748 x 10^6, and the energy in the flash vapor to the blow heat recovery is 50.367 x 10^6 for a total of 103.115 x 10^6. Rounding in the calculations causes the slight error in the balance.

MATERIAL BALANCES

Performing an energy balance around the blow tank provides valuable information for material balances in blow heat recovery, washer, and evaporator areas. Table IX shows the calculations for values necessary to perform material balances for the washer and evaporator areas.

Depending upon the steam flow to the digester and the yield and moisture content of the wood chips, the total heat available per blow will vary from 47.0 to 52.0 x 10^6 Btu/blow. This energy is in the 43,668 lb of steam

Material	lb/digester	Specific heat	T (220 - 32)	Btu
Pulp	36,825	.33	188	2.285 x 10^6
Total dissolved solids	61,200	.30	188	3.452 x 10^6
Total water	250,056	1.00	188	47.011 x 10^6
				Total Btu 52.748 x 10^6

VIII. Energy leaving blow tank to washers

Total material in the blow tank = pulp + total dissolved solids + water = 36,825 + 61,200 + 250,056 = 348,081 lb.

% blow tank pulp consistency = (pulp x 100)/total material = (36,825/348,081) x 100 = 10.6 (without dilution)

% liquor solids = [total dissolved solids/(total dissolved solids + water)]100 = [61,200/(61,200 + 250,056)]100 = 19.66%

Total dissolved solids produced per ton of pulp = dissolved solids produced/ton o.d. pulp = 61,200/18.41 = 3324 lb solids/ton o.d. pulp

IX. Calculations necessary for material balances for the washer and evaporator areas

vapor that flows into the blow heat recovery during the digester blow. If the blow lasts 15 min, then the average flow rate of blow vapors is 2911 lb/min. The flow from the digester 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 5240 lb/min. This maximum flow rate is the basis for proper sizing of the blow heat primary condenser. Additional steam and energy also come from blow tank padding steam, digester relief to the blow tank, and leaking direct steam valves to the digesters. It is important to include the additional energy in the condensing requirements for the blow heat condensers.

CONCLUSION

Without a proper understanding of the thermodynamics involved, one sometimes assumes the heat available for vaporization is the total heat going to the blow heat recovery. Such an assumption could result in a 20% error in the actual amount of energy going to the blow heat recovery. An error of this magnitude will normally overcome any margin of safety in the primary condenser and result in blow vapor release to the atmosphere. TJ

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