CAPE 3000 Design Project

CE 7 Detergent Powder Manufacture

Mass and Energy Balance Calculations

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**Materials Balance**

**General assumptions:**

* All moisture in the final product is as a result of manual water addition to the stream and water generated via the acid neutralisation reaction. Carbonate and sulphates are used in their anhydrous powder form as well as all other solid and liquid components having an insignificant moisture content.
* All impurities which may be present in the raw materials are within the final product as part of their raw material component, such as unreacted linear alkylbenzene sulphonic acid and its sodium salt containing unreacted linear alkylbenzene impurities.
* The rates at which fines and coarse agglomerates are removed from the fluid bed conditioner exits streams are assumed to be returned to the ploughshare mixer inlet at an equal rate.
* The exit streams of the screw conveyors are a homogenous mix of the relative components in their given quantities.
* All materials balances are assumed to be in continuous, steady-state flow.
* The materials balances performed on each process unit, other than the neutralisation reactor, are given as;

*Table 1: Detergent Powder Formulation (Dry Basis)*

|  |  |  |  |
| --- | --- | --- | --- |
| **Component** | **Percentage wt%** | **Fraction** | **Mass kg/h** |
| Zeolite A | 25 | 0.25 | 898.97 |
| Sodium Carbonate | 18 | 0.18 | 647.26 |
| Sodium Sulphate | 17.5 | 0.175 | 629.28 |
| Sodium Percarbonate | 12 | 0.12 | 431.51 |
| LAS Salt | 10 | 0.1 | 359.59 |
| Sodium Lauryl Sulphate | 5 | 0.05 | 179.79 |
| Non-ionics (Alkyl Ethoxylate) | 4 | 0.04 | 143.84 |
| TAED (Bleach activator) | 3 | 0.03 | 107.88 |
| Polycarboxylates (Sodium polyacrylate) | 2 | 0.02 | 71.92 |
| Perfume Encapsulates | 1 | 0.01 | 35.96 |
| Brighteners | 0.5 | 0.005 | 17.98 |
| Perfume Oil | 0.5 | 0.005 | 17.98 |
| Enzymes | 0.5 | 0.005 | 17.98 |
| Sud-suppressor (Silicon Oil) | 0.5 | 0.005 | 17.98 |
| CMC | 0.5 | 0.005 | 17.98 |
| **Total (Production)** | 100 | 1 | **3595.89** |

**1. Materials balance on drum mixer**

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*Figure 1: Block diagram of drum mixer*

No reactions take place in this continuous mixer and so the overall materials balance is relatively simple and given as;

S38 is the outlet for the final product, S37 is the liquid inlet for the sprayed-on perfume oil and S36 in the outlet of the 3rd overall process screw conveyor which transports the main powdered product as well as temperature-sensitive post-addition components such as enzymes, CMC and a feed from the 4th process screw conveyor.

**2. Materials balance on 4th screw conveyor**

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*Figure 2: Block diagram of 4th screw conveyor in process*

Streams 30, 31, 32 and 33 contain silicon oil, TAED, optical brighteners and perfume encapsulates respectively, therefore the overall materials balance is;

From the dry basis composition table (table 1) the mass flow rates for streams 30-33 respectively are given as;

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**3. Materials balance on 3rd screw conveyor**

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*Figure 3: Block diagram of 3rd screw conveyor in process*

***Assumptions:***

* S29 contains enzymes, protease and amylase, which are assumed to be in a homogenous mixture with ratio 1:1
* The S34 exit stream from the 4th screw conveyor feeds into a vessel which has an exit stream, S35, is assumed to have the same mass flow rate and composition as S34. (i.e. S34 = S35)

Both S36 and S35 (= S34) have been calculated from the previous two mass balances above. S29 is a stream containing enzymes. S28 contains CMC.

The overall materials balance is given as;

From table 1 and previous materials balances it can be determined that;

**4. Materials balance on vibrational sieve**

*Figure 4: Block diagram of vibrational sieve*

***Assumptions:***

* The vibrational sieve has a 98% efficiency.
* S26 feeds into a vessel which has an outlet stream, S27, which is assumed to be of the same mass flow rate and composition as S26. (i.e. S26 = S27)

S27 has been calculated as 3362.15 kg/hr in the previous materials balance, therefore, based upon the assumptions given (S26 = S27), the overall materials balance is given as;

based upon the assumption,

**5. Materials balance on fluid bed conditioner**

*Figure 5: Block diagram of fluid bed conditioner*

***Assumptions:***

* Total fines produced in gas exhaust stream is 10%.
* Feed to the conditioner is de-aerated (contains no air).
* No air or gases in the product stream leaving the conditioner.
* The powder enters the fluid bed conditioner with a free moisture content equal to the amount produced via the stoichiometric neutralisation reaction as well as a 2wt% excess of the ingredients for the reaction. This is calculated in the neutralisation reactor mass balance below.
* The fluid bed conditioner removes 100% of the free water in the powder.

**5.1. Materials balance on dry powder**

The overall balance for the dry powder material in the fluid bed dryer is;

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Based upon the assumption for the materials fines stream, S18 and S19 can be found from the materials balance over the vibrational sieve previously that determined S24.

However, this balance is not complete as the moisture content that has been removed in the fluid bed dryer must be added to correctly calculate S19. In the neutralisation reactor balance, this is found to be 22.27 kg/hr, therefore;

from this, the feed of the fluid bed conditioner, , can be found from;

**6. Materials balance on bag filter**



*Figure 6: Block diagram of bag filter*

***Assumptions:***

* Heating and cooling air are recovered completely from the bag filter.
* Bag filter efficiency is assumed to be 100%
* All moisture that has been removed from the powder in the fluid bed conditioner is assumed to pass through the filter with the air stream (S21) and be fully separated from the powder stream.

As the bag filter is assumed to be 100%, this means that all of the fines that enter the filter in S19 shall be removed and fed into S20 which shall be returned to the ploughshare mixer. As well as this the free water in the powder is assumed to be fully removed from the powder in the fluid bed dryer and passes straight through the bag filter in the air stream. Therefore, for the materials balance for the dry powder, the equation is;

**7. Materials balance on 1st screw conveyor into milling**



*Figure 7: Block diagram of 1st screw conveyor in process going into a miller*

***Assumptions:***

* Addition of sodium sulphate in stream S11 has been reduced from the amount given in table 1 due to its formation based on impurities in the neutralisation reaction.
* Addition of sodium carbonate in S12 has been calculated based upon only having a 5:1 stoichiometric ratio of carbonate to acid in the neutralisation reactor and thus S12 is a secondary carbonate addition point.
* The values given for S11 and S12 have been calculated as described based upon the neutralisation reactor materials balance.
* The milling process will reduce the sulphate and carbonate to sufficient particle size in one pass.

The overall balance is given as;

A 5:1 stoichiometric excess of carbonate in the neutralisation reactor must be subtracted from the overall mass flow rate (taking into account the amount that is used up in the reaction) to calculate the mass flow rate of S12. This is given as 415.48 kg/hr.

The sulphate that is formed in the neutralisation reaction must be subtracted from the total mass flow rate giving a final value of 326.35 kg/hr

**8. Materials balance on 2nd screw conveyor**



*Figure 8: Block diagram of 2nd screw conveyor in process*

The overall balance is given as;

S10 contains sodium percarbonate and from table 1 the mass flow rate for S10 is 435.51kg/hr. The value of S13 has been calculated in the previous materials balance and so the overall balance is;

**9. Materials balance on ploughshare mixer**

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*Figure 9: Block diagram of ploughshare mixer*

The overall balance is given as;

From table 1 and previous materials balances this gives;

**10. Materials balance on neutralisation reactor**

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*Figure 10: Block diagram of neutralisation reactor*

This unit involves a neutralization reaction and therefore the material’s balance is given by this formula:

***Assumptions:***

* HLAS contains 2mol% sulphuric acid as an impurity.
* Complete conversion of HLAS and sulphuric acid in the reactor.
* All reactions occur in their stoichiometric balances based upon number of moles of HLAS-related reactants.

Materials balance of the neutralisation reactor is best carried out on a molar basis. The basis of this calculation is that a 5:1 excess of Sodium Carbonate is fed as compared to the stoichiometric quantity requires to fully neutralise the HLAS.

As 359.589kg/h of LABS salt are required in the subsequent process units, based upon table 1 and the final product composition, and with a molecular weight of 347.49 kg/kmol is can be calculated that:

The reactions taking place in the reactor are as follows;

Main Reaction:

Side Reaction:

From the stoichiometry of the main reaction above, it can be seen that the required number of moles of HLAS required is 1.035 kmol/h, therefore the mass of HLAS required for this can be found by multiplying this value by its molecular weight, 326.49 kg/kmol, to get a mass of 336.89 kg/h. The kmoles of sodium carbonate required for this reaction would be 1.035/2 = 0.515 kmol/h. The kmoles of water and CO2 produced would be 0.515 kmol/h each.

From the assumption that the HLAS has 2mol% sulphuric acid content, it can be calculated that the sulphuric acid molar content of the S15 is;

Therefore, from the stoichiometry of the side reaction above, it can be seen that each reactant and component would have the same rate of either production or disappearance (0.0207 kmol/h).

Based upon each components molecular weight the relative mass flow rates can be determined as:

* HLAS stream =
* CO2 stream =
* Na2CO3 stream =
* Water stream = (based upon 2wt% assumption) =

**11. Materials balance on milling into vibrational sieve**

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*Figure 11: Block diagram of milling and vibrational sieving*

***Assumptions:***

* 90% of the initial feed carbonate is reduced to a size of less than 60 microns (the required size for the neutralisation reaction) meaning that 10% of the initial feed is sent to the recycle stream during the vibrational sieving.

The assumption that 90% of the initial feed being milled to a suitable degree for the process results in the following calculations for the materials balances.

Overall materials balance;

S4 = 289.72 kg/h

S3 = 318.69 kg/h

S2 = 28.97 kg/h

S1 = 289.72 kg/h

**Energy Balance**

**Energy Balance across CSTR**

The following Equation’s 12.1 and 12.2 represent the rate of energy required in order for the CSTR to remain at 323K.

Where Q = energy rate

= sum of enthalpy out

= enthalpy of neutralisation of components, which in this scenario, HLAS and Sulphuric acid are required to be neutralised.

= specific enthalpy based on the reference temperature 323K

The enthalpy of reaction in this case is equal to the sum of the enthalpy of neutralisation for both acids.

(12.1)

and(12.2)

**Enthalpy output of CSTR:**

Equation 12.3 is the calculations for enthalpies of each component leaving the CSTR.

= + + + +  (12.3)

Enthalpy of Sodium Sulphate:

* = 0.020637571 [-8.4249 (323-298) +( ) – 4.10 × 10-3 ()+

6.41× 10-6 ) - 5.21 × 10-9 ) + 2.16× 10-12 )

- 3.61× 10-16)]

Enthalpy of Carbon dioxide leaving the exhaust

* = 0.536576852[ 2.35 × 10-1(323-298) + 3.81 × 10-2 ( )+ 7.40 × 10-5 () - 2.23 × 10-7 ) + 2.34 × 10-10 ) – 1.15 × 10-12 ) + 2.17 × 10-17(]

Enthalpy of Linear alkyl benzene sulphonate leaving the CSTR:

* = 1.033301842 [511.36184 (323 – 298) + 0.02242624 ( )]

Enthalpy of water leaving the CSTR:

* = 1.235069736 [ -22.41701677 (323 – 298) + 0.876972156 ( ) - 0.002570393 () + 0.00000248383]

Enthalpy of Sodium Carbonate leaving the CSTR:

* = 2.146307408 [132.438453 (323-298) - + 0.017089275

- 0.0000636359 + 0.000000118977) - 1.09 × 10-11 ) + 3.93 1.09 × 10-14]

Total enthalpy output of the CSTR:

**= 22.23 MJ/hr**

**Enthalpy input of CSTR:**

The following calculations are for the input of the CSTR.

The heat of neutralisation of HLAS and sulphuric acid was first calculated with the formula (13.1)

* = 1.042837366 (12.6) + 0.020637571 (25.2) = 13660 kJ/h

Which was then summed up with the enthalpy of HLAS and sulphuric acid which was calculated as shown below.

* = 1.042837366 ]
* = 0.020637571 [26.004 1.03 × 10-6

The enthalpies of sodium carbonate and water was not calculated as it will sum up to zero because they are in their reference states.

Total enthalpy input for CSTR = **24.474 MJ/hr**

**Overall energy required to maintain constant temperature in the CSTR:**

Using the Enthalpy input and output values, the overall enthalpy change across the CSTR can be calculated using equation 12.1 as: **-2.239751222 MJ/hr**

**Energy Balance across the High Shear Mixer**

An energy balance is necessary across the mixer to calculate the energy required to heat all components to 50°C to achieve agglomeration. Cp values used in calculations are displayed in Appendix B.

Assumptions made:

* Adiabatic condition – Qin=Qout
* Cp values for Sodium Lauryl Sulphate, LABS, Zeolite 4A, Sodium Percarbonate, and alkyl alcohol ethoxylate are estimated using Kopp’s rule.
* Room temperature taken to be 25°C, in accordance with reference states.

The value for the enthalpy of S8 is was taken to be the value calculated for the mixture leaving the CSTR. The molar flow rates from the stream tables in Appendix A, Equation 2 and Values of enthalpy for S18, S20 and S25 were calculated using the relevant Cp values from Appendix B using the following method for each component of each stream:

This method was repeated for each of the components in S18, S20 and S25 and then they were combined yielding the following values for the energies of each stream:

For the high shear mixer, enthalpies of all streams except for the stream arriving from the CSTR can be neglected as they are fed in to the mixer in their reference states:

Where Qinput is the energy required to heat the mixer.

**Energy Balance across the Fluid Bed Conditioner**

**Appendix A**

**Appendix B**

Table X: The table shows the heat capacities for each of the component from references.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Component | Specific Heat (A+BT+CT2+DT3+ET4+FT5+GT6) | | | | | | | | |
| A | B | C | D | E | F | G | Unit | Reference |
| Sodium lauryl sulphate | 4.45E+02 | 2.24E-02 | - | - | - | - | - | J/mol | (CAPE, 2016) |
| Linear alkyl benzene sulphonate | 5.11E+02 | 2.24E-02 | - | - | - | - | - | J/mol | (CAPE, 2016) |
| Zeolite 4A | 2.57E+03 | 4.62E-01 | 5.07E+06 | - | - | - | - | J/mol | (CAPE, 2016) |
| Sodium percarbonate | 198.42 | - | - | - | - | - | - | J/mol | (CAPE, 2016) |
| Linear alkyl benzene sulphonic acid | 412 | - | - | - | - | - | - | J/mol | (CAPE, 2016) |
| Alkyl alcohol ethoxylate | 471.8 | - | - | - | - | - | - | J/mol | (CAPE, 2016) |
| Sodium sulphate | -8.42489709 | 1.33E+00 | -4.10E-03 | 6.41E-06 | -5.21E-09 | 2.16E-12 | -3.61E-16 | J/mol | (Yaws, 2009) |
| Sodium carbonate | 132.4384525 | -1.89E+00 | 1.71E-02 | -6.36E-05 | 1.19E-07 | -1.09E-10 | 3.93E-14 | J/mol | (Yaws, 2009) |
| Sodium polyacrylate | 106.26184 | 2.24E-02 | - | - | - | - | - | J/mol | (CAPE, 2016) |
| Carbon dioxide | 2.35E+01 | 3.81E-02 | 7.40E-05 | -2.23E-07 | 2.34E-10 | -1.15E-13 | 2.17E-17 | J/mol | (Yaws, 2009) |
| Water | -22.41701677 | 0.876972156 | -0.002570393 | 2.48E-06 | -22.41701677 | 0.876972156 | -0.002570393 | J/mol | (Yaws, 2009) |
| Sulfuric acid | 26.004 | 0.70337 | -0.0013856 | 1.03E-06 | - | - | - | J/mol | (Yaws, 2009) |