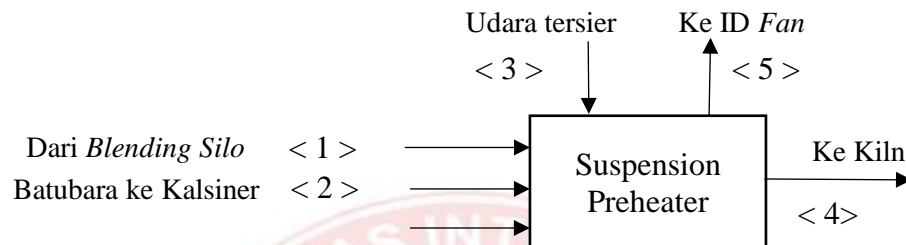


**LAMPIRAN A**  
**APPENDIKS NERACA MASSA RKC 4**

**Preheater**

Basis : 1 jam

- Preheater : Berfungsi untuk proses pemanasan awal sebelum masuk kedalam alat Rotary Kiln
- Udara Tersier : Udara panas dari cooler yang dimanfaatkan kembali untuk udara pembakaran di kalsiner



Umpan Masuk ke Preheater : 560 ton / jam  
: 560000 kg/jam

Komposisi umpan masuk preheater

| Komponen                       | %Massa |
|--------------------------------|--------|
| SiO <sub>2</sub>               | 13.1   |
| Al <sub>2</sub> O <sub>3</sub> | 3.69   |
| Fe <sub>2</sub> O <sub>3</sub> | 2.45   |
| CaO                            | 43     |
| MgO                            | 1.19   |
| H <sub>2</sub> O               | 0.39   |
| SO <sub>3</sub>                | 0.08   |
| Na                             | 0.12   |
| K                              | 0.32   |
| Cl                             | 0      |
| Total                          | 64.34  |

BM CaCO<sub>3</sub> : 100  
 BM MgCO<sub>3</sub> : 84  
 BM CaO : 56  
 BM MgO : 40  
 BM CO<sub>2</sub> : 44

% CaCO<sub>3</sub> : 76.8

%MgCO<sub>3</sub> : 2.5

Komposisi Umpan masuk preheater

| No.   | Komponen                       | Input  |             |            |
|-------|--------------------------------|--------|-------------|------------|
|       |                                | %Berat | Massa (ton) | Massa (kg) |
| 1     | SiO <sub>2</sub>               | 13.1   | 73.36       | 73360      |
| 2     | Al <sub>2</sub> O <sub>3</sub> | 3.69   | 20.664      | 20664      |
| 3     | Fe <sub>2</sub> O <sub>3</sub> | 2.45   | 13.72       | 13720      |
| 4     | CaCO <sub>3</sub>              | 76.79  | 430.024     | 430024     |
| 5     | MgCO <sub>3</sub>              | 2.5    | 14          | 14000      |
| 6     | H <sub>2</sub> O               | 0.39   | 2.184       | 2184       |
| 7     | SO <sub>3</sub>                | 0.08   | 0.448       | 448        |
| 8     | Na                             | 0.12   | 0.672       | 672        |
| 9     | K                              | 0.32   | 1.792       | 1792       |
| 10    | Cl                             | 0      | 0           | 0          |
| 11    | Impuritis                      | 0.56   | 3.136       | 3136       |
| Total |                                | 100    | 560         | 560000     |

Umpan Kering

H<sub>2</sub>O yang dilepas : 2.18 ton  
: 2184 kg

Umpan kering tanpa H<sub>2</sub>O : 557.816 ton  
: 557816 kg

asumsi debu keluar : 10% dari umpan kering  
Debu yang keluar : 55.7816 ton  
: 55781.6 kg

Umpan masuk Kalsiner : 502.034 ton  
: 502034 kg

Massa komponen masuk kalsiner

| Komponen                       | %Berat | Massa (ton) | Massa (kg) |
|--------------------------------|--------|-------------|------------|
| SiO <sub>2</sub>               | 13.15  | 66.02       | 66024      |
| Al <sub>2</sub> O <sub>3</sub> | 3.70   | 18.60       | 18598      |
| Fe <sub>2</sub> O <sub>3</sub> | 2.46   | 12.35       | 12348      |
| CaCO <sub>3</sub>              | 77.09  | 387.02      | 387022     |
| MgCO <sub>3</sub>              | 2.51   | 12.60       | 12600      |
| SO <sub>3</sub>                | 0.08   | 0.40        | 403        |

| Komponen  | %Berat | Massa (ton) | Massa (kg) |
|-----------|--------|-------------|------------|
| Na        | 0.12   | 0.60        | 605        |
| K         | 0.32   | 1.61        | 1613       |
| Cl        | 0.00   | 0.00        | 0          |
| Impuritis | 0.56   | 2.82        | 2822       |
| Total     | 100    | 502.03      | 502034     |

Derajat Kalsinasi : 95.0% data dari lab

Reaksi 1

Komponen yang mengalami kalsinasi

CaCO<sub>3</sub> Terkalsinasi : 368 ton  
: 367671 kg  
CaO terbentuk : 206 ton  
: 205895 kg  
CO<sub>2</sub> terbentuk : 162 Ton  
: 161775 kg  
CaCO<sub>3</sub> sisa : 19 ton  
: 19351 kg

Reaksi 2

MgCO<sub>3</sub> terkalsinasi : 12 ton  
: 11970 kg  
MgO terbentuk : 5.7 ton  
: 5700 kg  
CO<sub>2</sub> terbentuk : 6.27 ton  
: 6270 kg  
MgCO<sub>3</sub> sisa : 0.6 ton  
: 630 kg  
CO<sub>2</sub> hasil kalsinasi : 168 ton  
: 168045 kg

Input Batubara : 16.1 ton/jam  
: 16090 kg/jam

Komposisi Batubara yang masuk

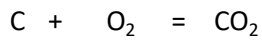
| Komponen       | %Berat | Massa (ton) | Massa (kg) |
|----------------|--------|-------------|------------|
| C              | 47.62  | 7.66        | 7662       |
| H <sub>2</sub> | 5.93   | 0.95        | 954        |
| N <sub>2</sub> | 0.86   | 0.14        | 138        |
| O <sub>2</sub> | 25.96  | 4.18        | 4177       |
| S              | 0.13   | 0.02        | 21         |

Asumsi : Reaksi pembakaran berlangsung secara sempurna, dimana derajat kesempurnaan reaksinya adalah 100%

| Komponen                | %Berat | Massa (ton) | Massa (kg) |
|-------------------------|--------|-------------|------------|
| moist(H <sub>2</sub> O) | 14.8   | 2.38        | 2381       |
| Ash                     | 4.7    | 0.76        | 756        |
| Total                   | 100    | 16.09       | 16090      |

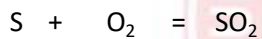
BM C : 12  
 BM H<sub>2</sub>O : 18  
 BM H<sub>2</sub> : 2  
 BM SO<sub>2</sub> : 64  
 BM S : 32  
 BM O<sub>2</sub> : 32  
 BM CO<sub>2</sub> : 44

Reaksi 1



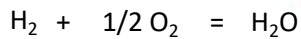
CO<sub>2</sub> terbentuk : 28.1 ton  
 : 28094.2 kg  
 O<sub>2</sub> yang diperlukan : 20.4 ton  
 : 20432.2 kg

Reaksi 2



SO<sub>2</sub> terbentuk : 0.04 ton  
 : 41.834 kg  
 O<sub>2</sub> yang diperlukan : 0.02 ton  
 : 20.917 kg

Reaksi 3



H<sub>2</sub>O yang terbentuk : 8.59 ton  
 : 8587.23 kg  
 O<sub>2</sub> yang terbentuk : 7.63 ton  
 : 7633.1 kg

Total O<sub>2</sub> yang diperlukan untuk reaksi : 28.1 ton  
 : 28086.2 kg  
 Komposisi O<sub>2</sub> pada batubara : 4.18 ton  
 : 4177 kg  
 Kebutuhan O<sub>2</sub> teoritis : Kebutuhan O<sub>2</sub> dalam reaksi - O<sub>2</sub> pada batubara  
 : 23.91 ton

: 23909 kg  
 Udara pembakaran yang digunakan 3.09% excess  
 Kebutuhan O<sub>2</sub> sesungguhnya : 103.09% x kebutuhan O<sub>2</sub> teoritis  
 : 24.6 ton  
 : 24648 kg  
 udara yang dibutuhkan : 100/21 x Kebutuhan O<sub>2</sub> sesungguhnya  
 Udara Tersier : 117 ton  
 : 117371 kg  
 N<sub>2</sub> didalam udara : 92.7 ton  
 : 92723.4 kg  
 O<sub>2</sub> sisa pembakaran : Kebutuhan O<sub>2</sub> sesungguhnya - Kebutuhan O<sub>2</sub> teoritis  
 : 0.7 ton  
 : 739 kg

Komposisi gas hasil pembakaran

| Komponen         | Massa (ton) | Massa(kg) |
|------------------|-------------|-----------|
| CO <sub>2</sub>  | 28.09       | 28094     |
| N <sub>2</sub>   | 92.72       | 92723     |
| H <sub>2</sub> O | 8.59        | 8587      |
| SO <sub>2</sub>  | 0.04        | 42        |
| Total            | 129.45      | 129447    |

Komposisi Output Preheater

| Komponen                       | Massa (ton) | Massa (kg) |
|--------------------------------|-------------|------------|
| SiO <sub>2</sub>               | 66.02       | 66024      |
| Al <sub>2</sub> O <sub>3</sub> | 18.60       | 18598      |
| Fe <sub>2</sub> O <sub>3</sub> | 12.35       | 12348      |
| CaCO <sub>3</sub> sisa         | 19.35       | 19351      |
| MgCO <sub>3</sub> sisa         | 0.63        | 630        |
| CaO                            | 205.90      | 205895     |
| MgO                            | 5.70        | 5700       |
| SO <sub>3</sub>                | 0.40        | 403        |
| Na <sub>2</sub> O              | 0.60        | 605        |
| K <sub>2</sub> O               | 1.61        | 1613       |
| Cl                             | 0.00        | 0          |
| Impuritis                      | 2.82        | 2822       |
| Ash                            | 0.76        | 756        |
| Total                          | 334.75      | 334746     |

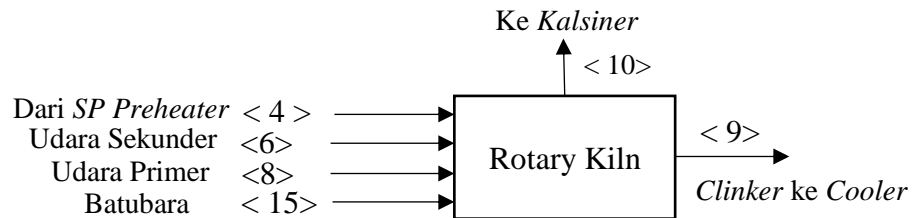
Mass Balance Preheater

| Input                          |                        |           | Output                          |               |             |
|--------------------------------|------------------------|-----------|---------------------------------|---------------|-------------|
| Komponen                       | Dari Blending Silo <1> |           | Komponen                        | Kiln Feed <4> |             |
|                                | xmass                  | mass (kg) |                                 | xmass         | mass (kg)   |
| SiO <sub>2</sub>               | 0.131                  | 73360     | SiO <sub>2</sub>                | 0.197         | 66024       |
| Al <sub>2</sub> O <sub>3</sub> | 0.037                  | 20664     | Al <sub>2</sub> O <sub>3</sub>  | 0.056         | 18598       |
| Fe <sub>2</sub> O <sub>3</sub> | 0.025                  | 13720     | Fe <sub>2</sub> O <sub>3</sub>  | 0.037         | 12348       |
| CaCO <sub>3</sub>              | 0.768                  | 430024    | CaCO <sub>3</sub> sisa          | 0.058         | 19351       |
| MgCO <sub>3</sub>              | 0.025                  | 14000     | MgCO <sub>3</sub> sisa          | 0.002         | 630         |
| H <sub>2</sub> O               | 0.004                  | 2184      | CaO                             | 0.615         | 205895      |
| SO <sub>3</sub>                | 0.001                  | 448       | MgO                             | 0.017         | 5700        |
| Na                             | 0.001                  | 672       | SO <sub>3</sub>                 | 0.001         | 403         |
| K                              | 0.003                  | 1792      | Na <sub>2</sub> O               | 0.002         | 605         |
| Cl                             | 0.000                  | 0         | K <sub>2</sub> O                | 0.005         | 1613        |
| Impuritis                      | 0.006                  | 3136      | Cl                              | 0.000         | 0           |
| Total                          | 1                      | 560000    | Impuritis                       | 0.008         | 2822        |
| Komponen                       | Batubara Kalsiner <2>  |           | Ash                             | 0.002         | 756         |
|                                | xmass                  | mass (kg) | Total                           | 1             | 334746      |
| C                              | 0.4762                 | 7662      | Komponen                        | GHP <5>       |             |
| H <sub>2</sub>                 | 0.0593                 | 954       |                                 | xmass         | mass (kg)   |
| N <sub>2</sub>                 | 0.0086                 | 138       | CO <sub>2</sub>                 | 0.2170        | 28094       |
| O <sub>2</sub>                 | 0.2596                 | 4177      | N <sub>2</sub>                  | 0.7163        | 92723       |
| S                              | 0.0013                 | 21        | H <sub>2</sub> O                | 0.0663        | 8587        |
| moist(H <sub>2</sub> O)        | 0.148                  | 2381      | SO <sub>2</sub>                 | 0.0003        | 42          |
| Ash                            | 0.047                  | 756       | Total                           | 1             | 129447      |
| Total                          | 1                      | 16090     | CO <sub>2</sub> hasil kalsinasi |               | 168045.0288 |
| Komponen                       | Udara Tersier <3>      |           | O <sub>2</sub> sisa GHP         |               | 739         |
|                                | xmass                  | mass (kg) | Uap H <sub>2</sub> O            |               | 2184        |
| O <sub>2</sub>                 | 0.79                   | 92723     | N <sub>2</sub> di batubara      |               | 138         |
| N <sub>2</sub>                 | 0.21                   | 24648     | H <sub>2</sub> O di batubara    |               | 2381        |
| Total                          | 1                      | 117371    | Debu                            |               | 55781.6     |
| <b>Total</b>                   | <b>693461</b>          |           | <b>Total</b>                    | <b>693461</b> |             |

## APPENDIKS NERACA MASSA

### Rotary Kiln

Neraca Massa



Rotary Kiln : Berfungsi untuk proses pembakaran kiln feed ,terjadinya kalsinasi sebesar 100% , dan terjadi proses klinkerisasi yang membentuk  $C_2S, C_3S, C_3A$ , dan  $C_4AF$

Komposisi Kiln Feed

| No.   | Komponen                       | Input  |             |            |
|-------|--------------------------------|--------|-------------|------------|
|       |                                | xmass  | Massa (ton) | Massa (kg) |
| 1     | SiO <sub>2</sub>               | 0.1972 | 66.02       | 66024      |
| 2     | Al <sub>2</sub> O <sub>3</sub> | 0.0556 | 18.60       | 18598      |
| 3     | Fe <sub>2</sub> O <sub>3</sub> | 0.0369 | 12.35       | 12348      |
| 4     | CaCO <sub>3</sub> sisa         | 0.0578 | 19.35       | 19351      |
| 5     | MgCO <sub>3</sub> sisa         | 0.0019 | 0.63        | 630        |
| 6     | CaO                            | 0.6151 | 205.90      | 205895     |
| 7     | MgO                            | 0.0170 | 5.70        | 5700       |
| 8     | SO <sub>3</sub>                | 0.0012 | 0.40        | 403        |
| 9     | Na <sub>2</sub> O              | 0.0018 | 0.60        | 605        |
| 10    | K <sub>2</sub> O               | 0.0048 | 1.61        | 1613       |
| 11    | Cl                             | 0.0000 | 0.00        | 0          |
| 12    | Impuritis                      | 0.0084 | 2.82        | 2822       |
| 13    | Ash                            | 0.0023 | 0.76        | 756        |
| Total |                                | 1      | 334.75      | 334746     |

Kiln Feed : 334.75 ton

: 334746 kg

BM CaCO<sub>3</sub> : 100

BM MgCO<sub>3</sub> : 84

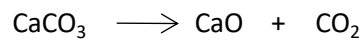
BM CaO : 56

BM MgO : 40

BM CO<sub>2</sub> : 44

BM C<sub>2</sub>S : 172  
 BM C<sub>3</sub>S : 228  
 BM C<sub>3</sub>A : 270  
 BM C<sub>4</sub>AF : 486  
 BM SiO<sub>2</sub> : 60  
 BM Al<sub>2</sub>O<sub>3</sub> : 102  
 BM Fe<sub>2</sub>O<sub>3</sub> : 160

Reaksi 1



CaCO<sub>3</sub> bereaksi : 19.35 ton  
                           : 19351 kg  
 CaO terbentuk : 10.8 ton  
                           : 10836.6 kg  
 CO<sub>2</sub> terbentuk : 8.51 ton  
                           : 8514.48 kg

Reaksi 2



MgCO<sub>3</sub> bereaksi : 0.63 ton  
                           : 630 kg  
 MgO terbentuk : 0.3 ton  
                           : 300 kg  
 CO<sub>2</sub> terbentuk : 0.33 ton  
                           : 330 kg  
 Total CO<sub>2</sub> hasil kalsinasi : 8.84 ton  
   : 8844.48 kg

Total CaO : CaO hasil kalsinasi di preheater + CaO hasil kalsinasi di Kiln  
                   : 217 ton  
                   : 216732 kg  
 Total MgO : MgO hasil kalsinasi di preheater + MgO hasil kalsinasi di Kiln  
                   : 6 ton  
                   : 6000 kg  
 Input Batubara : 23.5 ton  
                           : 23500 kg

Komposisi Batubara yang masuk

| Komponen       | %Berat | Massa (ton) | Massa (kg) |
|----------------|--------|-------------|------------|
| C              | 47.62  | 11.19       | 11191      |
| H <sub>2</sub> | 5.93   | 1.39        | 1394       |



| Komponen                | %Berat | Massa (ton) | Massa (kg) |
|-------------------------|--------|-------------|------------|
| N <sub>2</sub>          | 0.86   | 0.20        | 202        |
| O <sub>2</sub>          | 25.96  | 6.10        | 6101       |
| S                       | 0.13   | 0.03        | 31         |
| moist(H <sub>2</sub> O) | 14.8   | 3.48        | 3478       |
| Ash                     | 4.7    | 1.10        | 1105       |
| Total                   | 100    | 23.50       | 23500      |

Massa batubara kering : 20.02 ton

: 20022 kg

Asumsi : Reaksi pembakaran berlangsung secara sempurna, dimana derajat kesempurnaan reaksi adalah 100%

BM C : 12

BM H<sub>2</sub>O : 18

BM H<sub>2</sub> : 2

BM SO<sub>2</sub> : 64

BM S : 32

BM O<sub>2</sub> : 32

BM CO<sub>2</sub> : 44

Reaksi 1

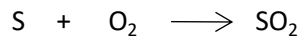


C bereaksi : 11.19 ton  
: 11190.70 kg

CO<sub>2</sub> terbentuk : 41.03 ton  
: 41033 kg

O<sub>2</sub> yang diperlukan : 29.8 ton  
: 29841.9 kg

Reaksi 2

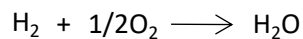


S bereaksi : 0.03 ton  
: 31 kg

SO<sub>2</sub> terbentuk : 0.06 ton  
: 61.1 kg

O<sub>2</sub> yang diperlukan : 0.03 ton  
: 30.6 ton

Reaksi 3



H<sub>2</sub> bereaksi : 1.39 ton  
: 1394 kg

$H_2O$  terbentuk : 12.5 ton  
 : 12542 kg  
 $O_2$  yang diperlukan : 11.1 ton  
 : 11148.4 kg  
 Total  $O_2$  yang diperlukan untuk reaksi : 41.0 ton  
 : 41020.8 kg  
 Komposisi  $O_2$  pada batubara : 6.10 ton  
 : 6101 kg  
 Kandungan  $O_2$  pada batubara belum bisa memenuhi kebutuhan  $O_2$  reaksi, sehingga diperlukan  $O_2$  tambahan ( $O_2$  teoritis)  
 Kebutuhan  $O_2$  teoritis : Kebutuhan  $O_2$  dalam reaksi -  $O_2$  pada batubara  
 : 34.92 ton  
 : 34920 kg  
 Udara pembakaran yang digunakan 6.00% excess  
 Kebutuhan  $O_2$  sesungguhnya : 106% x kebutuhan  $O_2$  teoritis  
 : 37 ton  
 : 37015.4 kg  
 Udara yang dibutuhkan : 100/21 x Kebutuhan  $O_2$  sesungguhnya  
 : 176 ton  
 : 176264 kg  
 $N_2$  didalam udara : 139 ton  
 : 139249 kg  
 $O_2$  sisa pembakaran : Kebutuhan  $O_2$  sesungguhnya - Kebutuhan  $O_2$  teoritis  
 : 2.10 ton  
 : 2095 kg  
 Kapasitas udara primer di kiln = 200 mbar  
 Kapasitas udara primer sebesar = 18167 m<sup>3</sup> dari spesifikasi motor penggerak  
 Densitas udara primer = 1.152 kg/m<sup>3</sup> 1.16498  
 Massa udara primer : 20.9 ton  
 : 20928.4 kg  
 Massa udara sekunder : 155.336 ton  
 : 155336 kg

Komposisi gas hasil pembakaran (GHP)

| Komponen | Massa (ton) | Massa(kg) |
|----------|-------------|-----------|
| $CO_2$   | 41.03       | 41033     |
| $N_2$    | 139.25      | 139249    |
| $H_2O$   | 12.54       | 12542     |

| Komponen        | Massa (ton) | Massa(kg) |
|-----------------|-------------|-----------|
| SO <sub>2</sub> | 0.06        | 61        |
| Total           | 192.88      | 192884    |

Total Ash (Abu) : Ash dari batubara + Ash dari kiln feed  
: 1.86 ton  
: 1861 kg  
Impuritis Kiln : 2.82 ton  
: 2822 kg

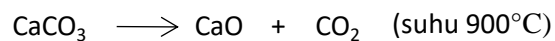
Komposisi Output Kiln

| No.   | Komponen                       | Massa (ton) | Massa(kg) |
|-------|--------------------------------|-------------|-----------|
| 1     | SiO <sub>2</sub>               | 66.02       | 66024     |
| 2     | Al <sub>2</sub> O <sub>3</sub> | 18.60       | 18598     |
| 3     | Fe <sub>2</sub> O <sub>3</sub> | 12.35       | 12348     |
| 4     | CaO                            | 216.73      | 216732    |
| 5     | MgO                            | 6.00        | 6000      |
| 6     | Impuritis                      | 2.82        | 2822      |
| 7     | Ash                            | 1.86        | 1861      |
| Total |                                | 324.38      | 324385    |

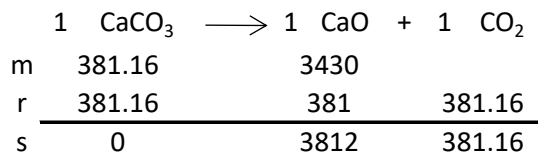
Reaksi

| Komponen          | Output Kiln |          |
|-------------------|-------------|----------|
|                   | xmass       | mass(kg) |
| C3A               | 0.0931      | 30200    |
| C4AF              | 0.1134      | 36785    |
| C2S               | 0.1844      | 59817    |
| C3S               | 0.5805      | 188305   |
| Na <sub>2</sub> O | 0.0001      | 32       |
| K <sub>2</sub> O  | 0.0041      | 1330     |
| SO <sub>3</sub>   | 0.0024      | 779      |
| MgO               | 0.0124      | 4022     |
| Impuritis         | 0.0097      | 3147     |
| Total             | 1           | 324385   |

Reaksi Kalsinasi



mol CaCO<sub>3</sub> mula-mula : 381  
mol CaO mula-mula : 3430

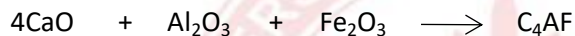


Massa CaCO<sub>3</sub> yang tersisa : 0 (CaCO<sub>3</sub> habis bereaksi )

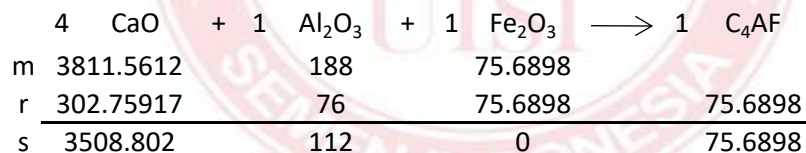
Massa CaO terbentuk : mol x BM  
 : 3812 x 56  
 : 213447 kg/jam

Massa CO<sub>2</sub> terbentuk : mol x BM  
 : 3812 x 44  
 : 167709 kg/jam

Reaksi I (Fe<sub>2</sub>O<sub>3</sub> habis bereaksi) (suhu 1000°C)

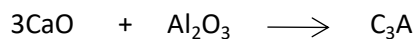


mol CaO mula-mula : 3812  
 mol Al<sub>2</sub>O<sub>3</sub> mula-mula : 188  
 mol Fe<sub>2</sub>O<sub>3</sub> mula-mula : 76



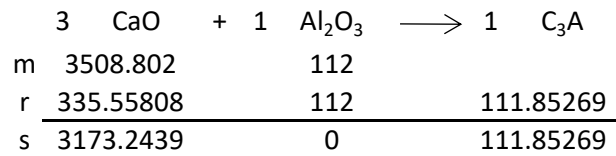
mol Fe<sub>2</sub>O<sub>3</sub> tersisa : 0 (Fe<sub>2</sub>O<sub>3</sub> habis bereaksi )  
 Massa CaO terbentuk : 3509 x 56  
 : 196493 kg/jam  
 Massa Al<sub>2</sub>O<sub>3</sub> terbentuk : 112 x 102  
 : 11409 kg/jam  
 Massa C<sub>4</sub>AF terbentuk : 76 x 486  
 : 36785 kg/jam

Reaksi II (Al<sub>2</sub>O<sub>3</sub> habis bereaksi) (suhu 1100°C)



mol CaO mula-mula : 3509

mol Al<sub>2</sub>O<sub>3</sub> mula-mula : 112

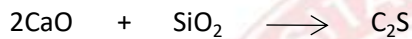


Massa Al<sub>2</sub>O<sub>3</sub> sisa : 0 (Al<sub>2</sub>O<sub>3</sub> habis bereaksi)

Massa CaO terbentuk : 3173 x 56  
: 177702 kg/jam

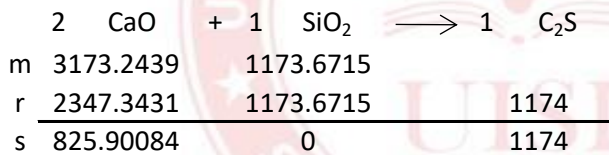
Massa C<sub>3</sub>A terbentuk : 112 x 270  
: 30200 kg/jam

Reaksi III (SiO<sub>2</sub> habis bereaksi) (suhu 1200°C)



mol CaO mula-mula : 3173

mol SiO<sub>2</sub> mula-mula : 1174

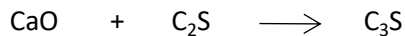


Massa SiO<sub>2</sub> sisa : 0 (SiO<sub>2</sub> habis bereaksi)

Massa CaO terbentuk : 826 x 56  
: 46250 kg/jam

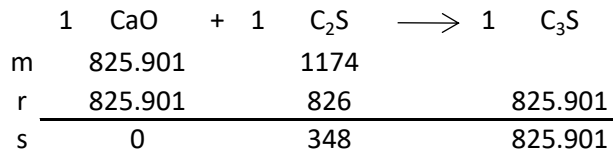
Massa C<sub>2</sub>S terbentuk : 1174 x 172  
: 201872 kg/jam

Reaksi IV (CaO habis bereaksi) (suhu 1300°C)



mol CaO mula-mula : 826

mol C<sub>2</sub>S mula-mula : 1174



Massa CaO sisa : 0 (CaO habis bereaksi)  
 Massa C<sub>2</sub>S sisa : 348 x 172  
 : 59817 kg/jam  
 Massa C<sub>3</sub>S terbentuk : 826 x 228  
 : 188305 kg/jam

Mass Balance Rotary Kiln

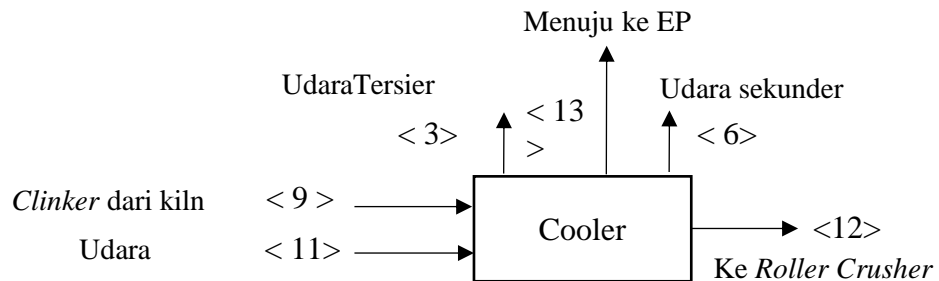
| Input                          |                    |           | Output                          |                 |           |
|--------------------------------|--------------------|-----------|---------------------------------|-----------------|-----------|
| Komponen                       | Dari Preheater <4> |           | Komponen                        | Cooler Feed <9> |           |
|                                | xmass              | mass (kg) |                                 | xmass           | mass (kg) |
| SiO <sub>2</sub>               | 0.1972             | 66024     | SiO <sub>2</sub>                | 0.2035          | 66024     |
| Al <sub>2</sub> O <sub>3</sub> | 0.0556             | 18598     | Al <sub>2</sub> O <sub>3</sub>  | 0.0573          | 18598     |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0369             | 12348     | Fe <sub>2</sub> O <sub>3</sub>  | 0.0381          | 12348     |
| CaCO <sub>3</sub> sisa         | 0.0578             | 19351     | CaO                             | 0.6681          | 216732    |
| MgCO <sub>3</sub> sisa         | 0.0019             | 630       | MgO                             | 0.0185          | 6000      |
| CaO                            | 0.6151             | 205895    | Impuritis                       | 0.0087          | 2822      |
| MgO                            | 0.0170             | 5700      | Ash                             | 0.0057          | 1861      |
| SO <sub>3</sub>                | 0.0012             | 403       | Total                           | 1               | 324385    |
| Na <sub>2</sub> O              | 0.0018             | 605       | Komponen                        | GHP <10>        |           |
| K <sub>2</sub> O               | 0.0048             | 1613      |                                 | xmass           | mass (kg) |
| Cl                             | 0.0000             | 0         | CO <sub>2</sub>                 | 0.2127          | 41033     |
| Impuritis                      | 0.0084             | 2822      | N <sub>2</sub>                  | 0.7219          | 139249    |
| Ash                            | 0.00226            | 756       | H <sub>2</sub> O                | 0.0650          | 12542     |
| Total                          | 1                  | 334746    | SO <sub>2</sub>                 | 0.0003          | 61        |
| Komponen                       | Batubara <15>      |           | Total                           | 1               | 192884    |
|                                | xmass              | mass (kg) | CO <sub>2</sub> hasil kalsinasi |                 | 8844.4752 |
| C                              | 0.4762             | 11191     | O <sub>2</sub> sisa             |                 | 2095      |
| H <sub>2</sub>                 | 0.0593             | 1394      | N <sub>2</sub> batubara         |                 | 202       |
| N <sub>2</sub>                 | 0.0086             | 202       | H <sub>2</sub> O batubara       |                 | 3478      |
| O <sub>2</sub>                 | 0.2596             | 6101      | Dust di udara                   |                 | 2621      |
| S                              | 0.0013             | 31        |                                 |                 |           |
| H <sub>2</sub> O               | 0.148              | 3478      |                                 |                 |           |

| Komponen       | Batubara <15>     |           |           |        |
|----------------|-------------------|-----------|-----------|--------|
|                | xmass             | mass (kg) |           |        |
| Ash            | 0.047             | 1105      |           |        |
| Total          | 1                 | 23500     |           |        |
| Komponen       | Udara Primer <8>  |           |           |        |
|                | xmass             | mass (kg) |           |        |
| O <sub>2</sub> | 0.21              | 4395      |           |        |
| N <sub>2</sub> | 0.79              | 16533     |           |        |
| Total          | 1                 | 20928     |           |        |
| Komponen       | Udara Skunder <6> |           |           |        |
|                | xmass             | mass (kg) |           |        |
| O <sub>2</sub> | 0.21              | 32620     |           |        |
| N <sub>2</sub> | 0.79              | 122715    |           |        |
| Total          | 1                 | 155336    |           |        |
| Total          |                   | 534510    | Total All | 534510 |



**APPENDIKS  
NERACA MASSA**

**Cooler**



| No.   | Komponen                       | xmass  | Massa(kg) |
|-------|--------------------------------|--------|-----------|
| 1     | SiO <sub>2</sub>               | 0.2035 | 66024     |
| 2     | Al <sub>2</sub> O <sub>3</sub> | 0.0573 | 18598     |
| 3     | Fe <sub>2</sub> O <sub>3</sub> | 0.0381 | 12348     |
| 4     | CaO                            | 0.6681 | 216732    |
| 5     | MgO                            | 0.0185 | 6000      |
| 6     | Impuritis                      | 0.0087 | 2822      |
| 7     | Ash                            | 0.0057 | 1861      |
| Total |                                | 1      | 324385    |

Cooler Feed : 324.38 ton  
                   : 324385 kg  
 Udara Sekunder : 155.336 ton  
                   : 155336 kg  
 Udara Tersier : 117 ton  
                   : 117371 kg  
 Flowrate udara : 2.14 kgudara/kgklinker  
 Kapasitas blower pada fan : 694.184 ton  
   : 694183.53 kg  
 Debu dari fan ke EP : 2% klinker panas  
                                   : 6.49 ton  
                                   : 6487.7 kg  
 Efisiensi EP : 99.85%  
 Klinker tersirkulasi : 6.47796 ton  
                                   : 6477.96 kg  
 Debu keluar EP : 0.01 ton



: 10 kg  
 Output Cooler : 324.38 ton  
 : 324375 kg  
 Sisa udara yang masuk ke Roller Mill : 421477 kg

Reaksi

| Komponen  | Output Cooler |          |
|-----------|---------------|----------|
|           | xmass         | mass(kg) |
| C3A       | 0.0931        | 30200    |
| C4AF      | 0.1134        | 36785    |
| C2S       | 0.1844        | 59817    |
| C3S       | 0.5805        | 188305   |
| Na2O      | 0.0001        | 32       |
| K2O       | 0.0041        | 1330     |
| SO3       | 0.0024        | 779      |
| MgO       | 0.0124        | 4022     |
| Impuritis | 0.0097        | 3147     |
| Total     | 1             | 324385   |

$C_3A$  : 1% x *Clinker*  
 : 302 kg/jam  
 $C_4AF$  : 1% x *Clinker*  
 : 368 kg/jam  
 $C_2S$  : 1% x *Clinker*  
 : 598 kg/jam  
 $C_3S$  : 1% x *Clinker*  
 : 1883 kg/jam  
 $Na_2O$  : 1% x *Clinker*  
 : 0 kg/jam  
 $K_2O$  : 1% x *Clinker*  
 : 13 kg/jam  
 $SO_3$  : 1% x *Clinker*  
 : 8 kg/jam  
 $MgO$  : 1% x *Clinker*  
 : 40 kg/jam  
 Impuritis : 1% x *Clinker*  
 : 31 kg/jam

Clinker ke crusher = Clinker masuk Cooler - Clinker yang terbawa ke EP  
 $C_3A$  = 30200 - 302 = 29898 kg/jam

|                   |   |        |   |      |   |        |        |
|-------------------|---|--------|---|------|---|--------|--------|
| C <sub>4</sub> AF | = | 36785  | - | 368  | = | 36417  | kg/jam |
| C <sub>2</sub> S  | = | 59817  | - | 598  | = | 59218  | kg/jam |
| C <sub>3</sub> S  | = | 188305 | - | 1883 | = | 186422 | kg/jam |
| Na <sub>2</sub> O | = | 32     | - | 0    | = | 32     | kg/jam |
| K <sub>2</sub> O  | = | 1330   | - | 13   | = | 1317   | kg/jam |
| SO <sub>3</sub>   | = | 779    | - | 8    | = | 771    | kg/jam |
| MgO               | = | 4022   | - | 40   | = | 3982   | kg/jam |
| Impuritis         | = | 3147   | - | 31   | = | 3115   | kg/jam |

Mass Balance Cooler

| Input                          |                       |           | Output                         |                    |           |
|--------------------------------|-----------------------|-----------|--------------------------------|--------------------|-----------|
| Komponen                       | Clinker dari Kiln <9> |           | Komponen                       | Output Cooler <12> |           |
|                                | xmass                 | mass (kg) |                                | xmass              | mass (kg) |
| SiO <sub>2</sub>               | 0.2035                | 66024     | SiO <sub>2</sub>               | 0.2035             | 66024     |
| Al <sub>2</sub> O <sub>3</sub> | 0.0573                | 18598     | Al <sub>2</sub> O <sub>3</sub> | 0.0573             | 18598     |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0381                | 12348     | Fe <sub>2</sub> O <sub>3</sub> | 0.0381             | 12348     |
| CaO                            | 0.6681                | 216732    | CaO                            | 0.6681             | 216732    |
| MgO                            | 0.0185                | 6000      | NgO                            | 0.0185             | 6000      |
| Impuritis                      | 0.0087                | 2822      | Impuritis                      | 0.0087             | 2822      |
| Ash                            | 0.0057                | 1861      | Ash                            | 0.0057             | 1861      |
| Total                          | 1                     | 324385    | Total                          | 1                  | 324385    |
| Komponen                       | Udara <11>            |           | Komponen                       | Udara Tersier <3>  |           |
|                                | xmass                 | mass (kg) |                                | xmass              | mass (kg) |
| O <sub>2</sub>                 | 0.21                  | 145779    | O <sub>2</sub>                 | 0.21               | 145779    |
| N <sub>2</sub>                 | 0.79                  | 548405    | N <sub>2</sub>                 | 0.79               | 548405    |
| Total                          | 1                     | 694184    | Total                          | 1                  | 117371    |
| Komponen                       | Udara Sekunder <6>    |           | Komponen                       | Udara Roller <12>  |           |
|                                | xmass                 | mass (kg) |                                | xmass              | mass (kg) |
| O <sub>2</sub>                 | 0.21                  | 145779    | O <sub>2</sub>                 | 0.21               | 88510     |
| N <sub>2</sub>                 | 0.79                  | 548405    | N <sub>2</sub>                 | 0.79               | 332966    |
| Total                          | 1                     | 155336    | Total                          | 1                  | 421477    |
|                                |                       |           | Debu keluar EP                 |                    | 10        |
| Total All                      |                       | 1018568   | Total All                      |                    | 1018578   |































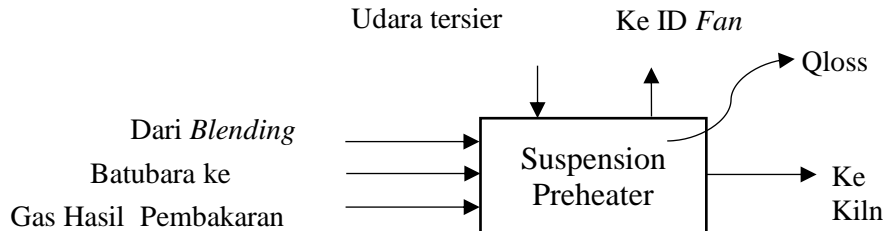






**LAMPIRAN B**  
**APPENDIKS NERACA ENERGI RKC 4**

**Preheater**



Neraca Energi dari blending silo

Temperature feed : 50 °C = 323 K  
Temperature reference : 25 °C = 298 K

Panas Sensible Raw Meal

| Komponen                       | Blending Silo <1> |              | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam)  |
|--------------------------------|-------------------|--------------|-------------|--------|-------------|
|                                | xmass             | mass(kg/jam) |             |        |             |
| SiO <sub>2</sub>               | 0.131             | 73360        | 0.7933      | 25     | 1454824.781 |
| Al <sub>2</sub> O <sub>3</sub> | 0.0369            | 20664        | 0.8194      | 25     | 423293.9693 |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0245            | 13720        | 0.6759      | 25     | 231849.3146 |
| CaCO <sub>3</sub>              | 0.7679            | 430024       | 0.8609      | 25     | 9255470.834 |
| MgCO <sub>3</sub>              | 0.025             | 14000        | 0.9600      | 25     | 336000      |
| H <sub>2</sub> O               | 0.0039            | 2184         | 1.8620      | 25     | 101663.2169 |
| SO <sub>3</sub>                | 0.0008            | 448          | 0.6570      | 25     | 7357.961454 |
| Na                             | 0.0012            | 672          | 1.1420      | 25     | 19185.6     |
| K                              | 0.0032            | 1792         | 0.9240      | 25     | 41395.2     |
| Cl                             | 0                 | 0            |             | 25     | 0           |
| impuritis                      | 0.0056            | 3136         | 1.0000      | 25     | 78400       |
| Total                          | 1                 | 560000       |             |        | 11949440.88 |

Panas Sensible udara tersier

Temperature feed : 898 °C = 1171 K  
Temperature reference : 25 °C = 298 K

Panas Sensible Udara Tersier

| Komponen       | Udara Tersier |              | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam) |
|----------------|---------------|--------------|-------------|--------|------------|
|                | xmass         | mass(kg/jam) |             |        |            |
| O <sub>2</sub> | 0.79          | 92723.4      | 1.024829    | 873    | 82957390.2 |

|                |      |          |           |     |             |
|----------------|------|----------|-----------|-----|-------------|
| N <sub>2</sub> | 0.21 | 24648.0  | 1.1035551 | 873 | 23745970.2  |
| Total          | 1    | 117371.4 |           |     | 106703360.4 |

Panas Sensible batubara

Temperature batubara : 70 °C = 343 K

Temperature reference : 25 °C = 298 K

Panas Sensible Batubara

| Komponen                        | Udara Batubara |              | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam) |
|---------------------------------|----------------|--------------|-------------|--------|------------|
|                                 | xmass          | mass(kg/jam) |             |        |            |
| C                               | 0.4762         | 7662         | 0.8990      | 45     | 309952.3   |
| H <sub>2</sub>                  | 0.0593         | 954          | 14.4305     | 45     | 309795.5   |
| N <sub>2</sub>                  | 0.0086         | 138          | 1.0273      | 45     | 3198.5     |
| O <sub>2</sub>                  | 0.2596         | 4177         | 0.9209      | 45     | 86547.6    |
| S                               | 0.0013         | 21           | 0.7618      | 45     | 717.0      |
| H <sub>2</sub> O <sub>(l)</sub> | 0.148          | 2381         | 4.2123      | 45     | 451388.4   |
| Ash                             | 0.047          | 756          | 1           | 45     | 34030.4    |
| Total                           | 1              | 16090        |             |        | 1195629.6  |

Neraca Energi Pembakaran Batubara

Massa Batubara : 16090 kg/jam

Heating Value : 4368 kkal/kg

Q Batubara : 16090 x 4368

: 7E+07 kkal/jam

: 294252993.2 kJ/jam

Panas Sensible produk preheater (range suhu 860-875 °C)

Temperature produk : 900 °C = 1173 K

Temperature reference : 25 °C = 298 K

Panas Sensible Produk Preheater

| Komponen                       | Udara Produk Preheater |              | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam)  |
|--------------------------------|------------------------|--------------|-------------|--------|-------------|
|                                | xmass                  | mass(kg/jam) |             |        |             |
| SiO <sub>2</sub>               | 0.1972                 | 66024        | 1.2135      | 875    | 70106386.97 |
| Al <sub>2</sub> O <sub>3</sub> | 0.0556                 | 18598        | 1.3218      | 875    | 21510232.49 |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0369                 | 12348        | 1.1305      | 875    | 12214014.78 |
| CaCO <sub>3</sub>              | 0.0578                 | 19351        | 1.3977      | 875    | 23665718.68 |
| MgCO <sub>3</sub>              | 0.0019                 | 630          | 0.2786      | 875    | 153558.3031 |
| CaO                            | 0.6151                 | 205895       | 1.1655      | 875    | 209976777.8 |
| MgO                            | 0.0170                 | 5700         | 1.2575      | 875    | 6272022.837 |

|                   |        |        |        |     |             |
|-------------------|--------|--------|--------|-----|-------------|
| SO <sub>3</sub>   | 0.0012 | 403    | 0.9714 | 875 | 342724.1384 |
| Na <sub>2</sub> O | 0.0018 | 605    | 1.5692 | 875 | 830400.5718 |
| K <sub>2</sub> O  | 0.0048 | 1613   | 1.2820 | 875 | 1809146.046 |
| Cl                | 0.0000 | 0      |        | 875 | 0           |
| impuritis         | 0.0084 | 2822   | 1.0000 | 875 | 2469600     |
| Ash               | 0.0023 | 756    | 1.0000 | 875 | 661701.25   |
| Total             | 1      | 334746 |        |     | 350012283.9 |

Panas Sensible GHP (gas hasil pembakaran)

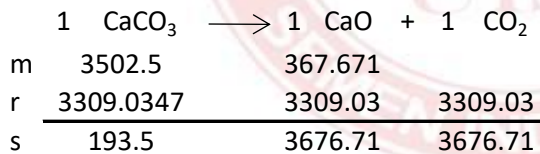
Temperature GHP : 390 °C = 663 K  
 Temperature reference : 25 °C = 298 K

Panas Sensible GHP

| Komponen                        | Gas Hasil Pembakaran |              | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam) |
|---------------------------------|----------------------|--------------|-------------|--------|------------|
|                                 | xmass                | mass(kg/jam) |             |        |            |
| CO <sub>2</sub>                 | 0.2170               | 28094        | 0.9852      | 365    | 10103105.3 |
| N <sub>2</sub>                  | 0.7163               | 92723        | 1.0568      | 365    | 17883106.0 |
| H <sub>2</sub> O <sub>(g)</sub> | 0.0663               | 8587         | 1.9350      | 365    | 3032426.1  |
| SO <sub>2</sub>                 | 0.0003               | 42           | 0.7794      | 365    | 5950.2     |
| Total                           | 1                    | 129447       |             |        | 31024587.6 |

Neraca Energi Pembakaran Batubara

Temperature reaktan : 780 °C = 1053 K  
 Temperature produk : 850 °C = 1123 K



Data heat of formation pada 25 °C ( ΔHf298 ) :

Heat of Formation H.Allaboun

| Komponen                       | ΔHf 298 (kJ/mol) |
|--------------------------------|------------------|
| CaCO <sub>3</sub>              | -1207            |
| CaO                            | -635             |
| CO <sub>2</sub>                | -393             |
| Al <sub>2</sub> O <sub>3</sub> | -1669            |
| Fe <sub>2</sub> O <sub>3</sub> | -822             |
| SiO <sub>2</sub>               | -908             |

|  |       |
|--|-------|
| $(\text{CaO})_4 \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ | -5080 |
| $(\text{CaO})_3 \cdot \text{Al}_2\text{O}_3$                             | -3561 |
| $(\text{CaO})_2 \cdot \text{SiO}_2$                                      | -2308 |
| $(\text{CaO})_3 \cdot \text{SiO}_2$                                      | -2931 |

$\Delta H$  reaktan

$$\begin{aligned} \text{CaCO}_3 &: m \times C_p \times \Delta T \\ &: 430024 \times 0.8609 \times (25 - 500) \\ &: (175,848,639.26) \text{ kJ/jam} \end{aligned}$$

$\Delta H$  produk

$$\begin{aligned} \text{CaO} &: m \times C_p \times \Delta T \\ &: 205895.49 \times 0.7867 \times (500 - 25) \\ &: 76,939,541.89 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CO}_2 &: m \times C_p \times \Delta T \\ &: 161775.03 \times 0.8194 \times (500 - 25) \\ &: 62,965,267.83 \text{ kJ/jam} \end{aligned}$$

$\Delta H_f$

$$\begin{aligned} \text{CaCO}_3 &: \text{mol} \times \Delta H_f \\ &: 3309.0347 \times -1207 \\ &: (3,994,004,858.76) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CaO} &: \text{mol} \times \Delta H_f \\ &: 3309.0347 \times -635 \\ &: (2,101,237,021.80) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CO}_2 &: \text{mol} \times \Delta H_f \\ &: 3309.0347 \times -393 \\ &: (1,300,450,629.24) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{Total } \Delta H \text{ reaktan} &: (175,848,639.26) \text{ kJ/jam} \\ \text{Total } \Delta H \text{ produk} &: 139,904,809.72 \text{ kJ/jam} \\ \text{Total } \Delta H_f &: 592,317,207.72 \text{ kJ/jam} \\ \text{Total } \Delta H_R &: 556,373,378.18 \text{ kJ/jam} \end{aligned}$$

Panas Sensible produk

| Komponen                        | Massa (kg/jam) | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam)    |
|---------------------------------|----------------|-------------|--------|---------------|
| CO <sub>2</sub> hasil kalsinasi | 168,045.03     | 0.985247065 | 365    | 60,431,543.05 |
| O <sub>2</sub> sisa GHP         | 738.79         | 0.9610648   | 365    | 259,160.69    |
| Uap H <sub>2</sub> O            | 2,184.00       | 1.934969459 | 365    | 1,542,480.25  |
| N <sub>2</sub> batubara         | 138.37         | 1.05679472  | 365    | 53,375.01     |
| H <sub>2</sub> O batubara       | 2,381.32       | 4.370290716 | 365    | 3,798,577.15  |
| Debu                            | 55,781.60      | 1           | 365    | 20,360,284.00 |
| Total                           | 229,269.12     |             |        | 86,445,420.16 |

Panas latent penguapan air pada 50 °C

$$H_v = 2592.1 \text{ kJ/kg}$$

$$H_l = 209.33 \text{ kJ/kg}$$

$$\lambda = 2,382.77 \text{ kJ/kg}$$

$$\begin{aligned}
 H_l &= m \times \lambda \\
 &= 4,565.32 \times 2,382.77 \\
 &= 10,878,107.54 \text{ kJ/jam}
 \end{aligned}$$

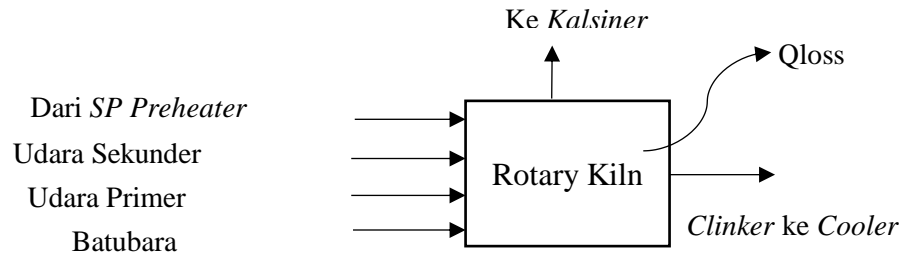
$$\begin{aligned}
 Q_{\text{loss}} &= (H \text{ input} - (H_s \text{ produk} + H_s \text{ Gas keluar preheater} + H_s \text{ GHP} + H_l \text{ penguapan air})) \\
 &= 970,474,802.26 - 478,360,399.21 \\
 &= 492,114,403.05
 \end{aligned}$$

Neraca Energi Prheater

| H input               |             | H output            |             |
|-----------------------|-------------|---------------------|-------------|
| Hs dari blending silo | 11,949,441  | Hs produk preheater | 350,012,284 |
| Hs udara tersier      | 106,703,360 | Hs GHP              | 31,024,588  |
| Hs batubara           | 1,195,630   | Hs gas keluar       | 86,445,420  |
|                       |             | HL                  | 10,878,108  |
| ΔHR Kals              | 556,373,378 | Q loss              | 492,114,403 |
| H Batubara            | 294,252,993 |                     |             |
| Total                 | 970,474,802 | Total               | 970,474,802 |

## APPENDIKS NERACA ENERGI

### Rotary Kiln



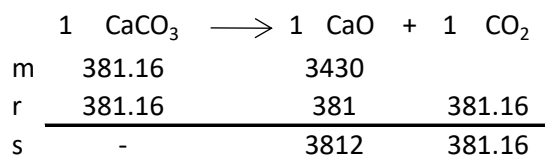
Neraca Energi dari preheater

|                         |   |      |      |      |   |
|-------------------------|---|------|------|------|---|
| Temperature bahan masuk | : | 900  | °C = | 1173 | K |
| Temperature produk      | : | 1350 | °C = | 1623 | K |
| Temperature reference   | : | 25   | °C = | 298  | K |

Panas Sensible Produk Preheater

| Komponen                       | Produk preheater |               | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam)         |
|--------------------------------|------------------|---------------|-------------|--------|--------------------|
|                                | xmass            | mass(kg/jam)  |             |        |                    |
| SiO <sub>2</sub>               | 0.1972           | 66024         | 1.2135      | 875    | 70106386.97        |
| Al <sub>2</sub> O <sub>3</sub> | 0.0556           | 18598         | 1.3218      | 875    | 21510232.49        |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0369           | 12348         | 1.1305      | 875    | 12214014.78        |
| CaCO <sub>3</sub>              | 0.0578           | 19351         | 1.3977      | 875    | 23665718.68        |
| MgCO <sub>3</sub>              | 0.0019           | 630           | 0.2786      | 875    | 153558.3031        |
| CaO                            | 0.6151           | 205895        | 1.1655      | 875    | 209976777.8        |
| MgO                            | 0.0170           | 5700          | 1.2575      | 875    | 6272022.837        |
| SO <sub>3</sub>                | 0.0012           | 403           | 0.9714      | 875    | 342724.1384        |
| Na <sub>2</sub> O              | 0.0018           | 605           | 1.5692      | 875    | 830400.5718        |
| K <sub>2</sub> O               | 0.0048           | 1613          | 1.2820      | 875    | 1809146.046        |
| Cl                             | 0.0000           | 0             |             | 875    | 0                  |
| impuritis                      | 0.0084           | 2822          | 1.0000      | 875    | 2469600            |
| Ash                            | 0.0023           | 756           | 1.0000      | 875    | 661701.25          |
| <b>Total</b>                   | <b>1</b>         | <b>334746</b> |             |        | <b>350012283.9</b> |

Panas kalsinasi lanjutan setelah di preheater





$\Delta H$  reaktan

$$\begin{aligned} \text{CaCO}_3 &: m \times C_p \times \Delta T \\ &: 19351 \times 1.346 \times (25 - 900) \\ &: (22,790,734.47) \text{ kJ/jam} \end{aligned}$$

$\Delta H$  produk

$$\begin{aligned} \text{CaO} &: m \times C_p \times \Delta T \\ &: 213447.43 \times 1.128 \times (900 - 25) \\ &: 210,672,610.06 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CO}_2 &: m \times C_p \times \Delta T \\ &: 16770.869 \times 1.087 \times (900 - 25) \\ &: 15,951,193.00 \text{ kJ/jam} \end{aligned}$$

$\Delta H_f$

$$\begin{aligned} \text{CaCO}_3 &: m \times \Delta H_f \\ &: 381.16 \times -1207 \\ &: (460,055,435.55) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CaO} &: m \times \Delta H_f \\ &: 381 \times -635 \\ &: (242,034,135.52) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CO}_2 &: m \times \Delta H_f \\ &: 381.16 \times -393 \\ &: (149,794,354.74) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{Total } \Delta H \text{ reaktan} &: (22,790,734.47) \\ \text{Total } \Delta H \text{ produk} &: 226,623,803.05 \\ \text{Total } \Delta H_f &: 68,226,945.29 \\ \text{Total } \Delta H_R &: 272,060,013.87 \end{aligned}$$

Panas enthalpy reaksi pembentukan klinker

Reaksi I

|   |   |          |   |   |                                |   |   |                                |   |   |                   |
|---|---|----------|---|---|--------------------------------|---|---|--------------------------------|---|---|-------------------|
|   | 4 | CaO      | + | 1 | Al <sub>2</sub> O <sub>3</sub> | + | 1 | Fe <sub>2</sub> O <sub>3</sub> | → | 1 | C <sub>4</sub> AF |
| m |   | 3,811.56 |   |   | 187.54                         |   |   | 75.69                          |   |   |                   |
| r |   | 302.76   |   |   | 75.69                          |   |   | 75.69                          |   |   | 75.69             |
| s |   | 3,508.80 |   |   | 111.85                         |   |   | -                              |   |   | 75.69             |

$\Delta H$  reaktan

$$\text{CaO} : m \times C_p \times \Delta T$$

$$\begin{aligned}
 & : 213447.43 \quad 1.128 \quad ( 25 - 1000 ) \\
 & : (234,749,479.78) \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{Al}_2\text{O}_3 & : m \quad x \quad C_p \quad x \quad \Delta T \\
 & : 19129.334 \quad 1.282 \quad ( 25 - 1000 ) \\
 & : (23,910,710.55) \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{Fe}_2\text{O}_3 & : m \quad x \quad C_p \quad x \quad \Delta T \\
 & : 12110.367 \quad 1.087 \quad ( 25 - 1000 ) \\
 & : (12,834,869.53) \text{ kJ/jam}
 \end{aligned}$$

$\Delta H$  produk

$$\begin{aligned}
 \text{C}_4\text{AF} & : m \quad x \quad C_p \quad x \quad \Delta T \\
 & : 36,785.24 \quad 3.494 \quad ( 1000 - 25 ) \\
 & : 125,314,435.35 \text{ kJ/jam}
 \end{aligned}$$

$\Delta H_f$

$$\begin{aligned}
 \text{CaO} & : \text{mol} \quad x \quad \Delta H_f \\
 & : 302.76 \quad -635 \\
 & : (192,252,073.54) \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{Al}_2\text{O}_3 & : \text{mol} \quad x \quad \Delta H_f \\
 & : 75.69 \quad -1669 \\
 & : (126,326,264.07) \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{Fe}_2\text{O}_3 & : \text{mol} \quad x \quad \Delta H_f \\
 & : 75.69 \quad -822 \\
 & : (62,217,009.63) \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{C}_4\text{AF} & : \text{mol} \quad x \quad \Delta H_f \\
 & : 75.69 \quad -5080 \\
 & : (384,504,147.09) \text{ kJ/jam}
 \end{aligned}$$

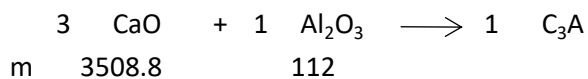
$$\text{Total } \Delta H \text{ reaktan} : (271,495,059.86) \text{ kJ/jam}$$

$$\text{Total } \Delta H \text{ produk} : 125,314,435.35 \text{ kJ/jam}$$

$$\text{Total } \Delta H_f : 3,708,799.84 \text{ kJ/jam}$$

$$\text{Total } \Delta H_R : (142,471,824.67) \text{ kJ/jam}$$

Reaksi II



|   |        |     |        |
|---|--------|-----|--------|
| r | 335.6  | 112 | 111.85 |
| s | 3173.2 | -   | 111.85 |

$\Delta H$  reaktan

$$\begin{aligned} \text{CaO} &: m \times C_p \times \Delta T \\ &: 196492.91 \times 1.128 \times (25 - 1100) \\ &: (238,267,306.34) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{Al}_2\text{O}_3 &: m \times C_p \times \Delta T \\ &: 11408.975 \times 1.282 \times (25 - 1100) \\ &: (15,723,278.56) \text{ kJ/jam} \end{aligned}$$

$\Delta H$  produk

$$\begin{aligned} \text{C}_3\text{A} &: m \times C_p \times \Delta T \\ &: 30,200.23 \times 1.282 \times (1100 - 25) \\ &: 41,620,443.25 \text{ kJ/jam} \end{aligned}$$

$\Delta H_f$

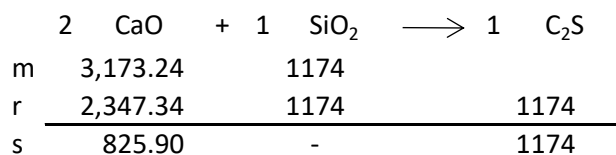
$$\begin{aligned} \text{CaO} &: m \times \Delta H_f \\ &: 335.56 \times -635 \\ &: (213,079,381.51) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{Al}_2\text{O}_3 &: m \times \Delta H_f \\ &: 112 \times -1669 \\ &: (186,682,145.80) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{C}_3\text{A} &: m \times \Delta H_f \\ &: 111.85 \times -3561 \\ &: (398,307,442.29) \text{ kJ/jam} \end{aligned}$$

|                          |   |                         |
|--------------------------|---|-------------------------|
| Total $\Delta H$ reaktan | : | (253,990,584.90) kJ/jam |
| Total $\Delta H$ produk  | : | 41,620,443.25 kJ/jam    |
| Total $\Delta H_f$       | : | 1,454,085.02 kJ/jam     |
| Total $\Delta H_R$       | : | (210,916,056.63) kJ/jam |

Reaksi III



$\Delta H$  reaktan

$$\begin{aligned} \text{CaO} & : m \times C_p \times \Delta T \\ & : 177,701.66 \times 1.128 \times (25 - 1200) \\ & : (235,525,780.81) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{SiO}_2 & : m \times C_p \times \Delta T \\ & : 70,420.29 \times 1.175 \times (25 - 1200) \\ & : (97,224,016.91) \text{ kJ/jam} \end{aligned}$$

$\Delta H$  produk

$$\begin{aligned} \text{C}_2\text{S} & : m \times C_p \times \Delta T \\ & : 201,871.51 \times 1.219 \times (1200 - 25) \\ & : 289,145,605.37 \text{ kJ/jam} \end{aligned}$$

$\Delta H_f$

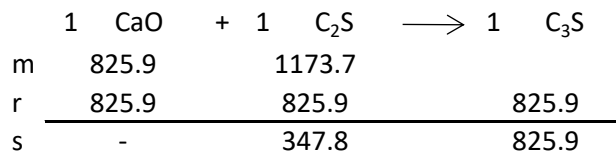
$$\begin{aligned} \text{CaO} & : \text{mol} \times \Delta H_f \\ & : 2,347.34 \times -635 \\ & : (1,490,562,866.83) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{SiO}_2 & : \text{mol} \times \Delta H_f \\ & : 1174 \times -908 \\ & : (1,065,693,766.21) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{C}_2\text{S} & : \text{mol} \times \Delta H_f \\ & : 1174 \times -2308 \\ & : (2,708,833,934.37) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{Total } \Delta H \text{ reaktan} & : (332,749,797.72) \text{ kJ/jam} \\ \text{Total } \Delta H \text{ produk} & : 289,145,605.37 \text{ kJ/jam} \\ \text{Total } \Delta H_f & : (152,577,301.33) \text{ kJ/jam} \\ \text{Total } \Delta H_R & : (196,181,493.68) \text{ kJ/jam} \end{aligned}$$

Reaksi IV



$\Delta H$  reaktan

$$\begin{aligned} \text{CaO} & : m \times C_p \times \Delta T \\ & : 46,250.45 \times 1.128 \times (25 - 1300) \\ & : (66,517,393) \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned}
 C_2S & : m \times C_p \times \Delta T \\
 & : 201,871.5 \times 1.219 \times (25 - 1300) \\
 & : (313,753,741.99) \text{ kJ/jam}
 \end{aligned}$$

$\Delta H$  produk

$$\begin{aligned}
 C_3S & : m \times C_p \times \Delta T \\
 & : 188,305.4 \times 1.165 \times (1300 - 25) \\
 & : 279,704,120.89 \text{ kJ/jam}
 \end{aligned}$$

$\Delta H_f$

$$\begin{aligned}
 CaO & : mol \times \Delta H_f \\
 & : 825.9 \times -635 \\
 & : (524,447,033.32) \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 C_2S & : mol \times \Delta H_f \\
 & : 825.9 \times -2308 \\
 & : ##### \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 C_3S & : mol \times \Delta H_f \\
 & : 825.9 \times -2931 \\
 & : ##### \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{Total } \Delta H \text{ reaktan} & : (380,271,134.92) \text{ kJ/jam} \\
 \text{Total } \Delta H \text{ produk} & : 279,704,120.89 \text{ kJ/jam} \\
 \text{Total } \Delta H_f & : 9,910,810.08 \text{ kJ/jam} \\
 \text{Total } \Delta H_R & : (90,656,203.95) \text{ kJ/jam}
 \end{aligned}$$

$$\text{Total } \Delta H_R \text{ (reaksi kalsinasi + klinkerisasi)} = (368,165,565.06) \text{ kJ/jam}$$

Neraca Energi pembakaran batubara

$$\begin{aligned}
 \text{Massa batubara} & : 20,022 \text{ kg/jam} \\
 \text{Heating Value} & : 4,368 \text{ kkal/kg} \\
 \text{H batubara} & : m \times \text{Heating value} \\
 & : 20,022 \times 4,368 \\
 & : 87,456,096.0 \text{ kkal/jam} \\
 & : 366,161,182.73 \text{ kJ/jam}
 \end{aligned}$$

$$\text{Temperature batubara} : 70 \text{ }^\circ\text{C} = 343 \text{ K}$$

$$\text{Temperature reference} : 25 \text{ }^\circ\text{C} = 298 \text{ K}$$

Panas Sensible Batubara

| Komponen                        | Batubara <15> |              | Cp(kJ/kg.K) | $\Delta T$ (K) | Hs(kJ/jam)   |
|---------------------------------|---------------|--------------|-------------|----------------|--------------|
|                                 | xmass         | mass(kg/jam) |             |                |              |
| C                               | 0.4762        | 11,190.70    | 0.8990      | 45             | 452,695.99   |
| H <sub>2</sub>                  | 0.0593        | 1,393.55     | 14.4305     | 45             | 904,933.96   |
| N <sub>2</sub>                  | 0.0086        | 202.10       | 1.0273      | 45             | 9,343.14     |
| O <sub>2</sub>                  | 0.2596        | 6,100.60     | 0.9209      | 45             | 252,811.48   |
| S                               | 0.0013        | 30.55        | 0.7618      | 45             | 1,047.24     |
| H <sub>2</sub> O <sub>(l)</sub> | 0.1480        | 3,478.00     | 4.2123      | 45             | 659,268.26   |
| Ash                             | 0.0470        | 1,104.50     | 1           | 45             | 49,702.50    |
| Total                           | 1             | 23,500.00    |             |                | 2,329,802.56 |

Temperature udara sekunder : 898 °C = 1171 K

Temperature reference : 25 °C = 298 K

Panas Sensible Udara sekunder

| Komponen       | Udara sekunder <6> |              | Cp(kJ/kg.K) | $\Delta T$ (K) | Hs(kJ/jam)    |
|----------------|--------------------|--------------|-------------|----------------|---------------|
|                | xmass              | mass(kg/jam) |             |                |               |
| O <sub>2</sub> | 0.21               | 32,620.47    | 1.02482896  | 873            | 29,184,740.4  |
| N <sub>2</sub> | 0.79               | 122,715.10   | 1.103555104 | 873            | 118,224,167.7 |
| Total          | 1                  | 155,335.57   |             |                | 147,408,908.1 |

Temperature udara primer : 30 °C = 303 K

Temperature reference : 25 °C = 298 K

Panas Sensible Udara primer

| Komponen       | Udara primer <8> |              | Cp(kJ/kg.K) | $\Delta T$ (K) | Hs(kJ/jam) |
|----------------|------------------|--------------|-------------|----------------|------------|
|                | xmass            | mass(kg/jam) |             |                |            |
| O <sub>2</sub> | 0.21             | 4,394.96     | 0.9158776   | 5              | 20,126.23  |
| N <sub>2</sub> | 0.79             | 16,533.42    | 1.02365744  | 5              | 84,622.81  |
| Total          | 1                | 20,928.38    |             |                | 104,749.04 |

Temperature klinker : 1350 °C = 1623 K

Temperature reference : 25 °C = 298 K

Panas Sensible produk klinker

| Komponen          | Batubara <15> |              | Cp(kJ/kg.K) | $\Delta T$ (K) | Hs(kJ/jam)    |
|-------------------|---------------|--------------|-------------|----------------|---------------|
|                   | xmass         | mass(kg/jam) |             |                |               |
| C <sub>3</sub> A  | 0.0931        | 30,200.23    | 1.692946841 | 1325           | 67,743,777.7  |
| C <sub>4</sub> AF | 0.1134        | 36,785.24    | 3.493836329 | 1325           | 170,291,127.1 |
| C <sub>2</sub> S  | 0.1844        | 59,816.56    | 1.2190042   | 1325           | 96,614,548.3  |
| C <sub>3</sub> S  | 0.5805        | 188,305.39   | 1.165359891 | 1325           | 290,762,704   |
| Na <sub>2</sub> O | 0.0001        | 32.44        | 1.622277247 | 1325           | 69,727.1      |

|                  |        |           |             |      |             |
|------------------|--------|-----------|-------------|------|-------------|
| K <sub>2</sub> O | 0.0041 | 1,329.98  | 1.476332972 | 1325 | 2,601,624.3 |
| SO <sub>3</sub>  | 0.0024 | 778.52    | 1.002107147 | 1325 | 1,033,717.4 |
| MgO              | 0.0124 | 4,022.37  | 1.320991164 | 1325 | 7,040,410.9 |
| impuritis        | 0.0097 | 3,146.53  | 1           | 1325 | 4,169,156.0 |
| Total            | 1      | 324,384.8 |             |      | 640,326,793 |

Temperature gas hasil pembakaran : 898 °C = 1171 K

Temperature reference : 25 °C = 298 K

Panas Sensible GHP

| Komponen            | GHP <10> |              | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam)  |
|---------------------|----------|--------------|-------------|--------|-------------|
|                     | xmass    | mass(kg/jam) |             |        |             |
| CO <sub>2</sub>     | 0.21     | 41,032.57    | 1.11833562  | 873    | 40,060,382  |
| N <sub>2</sub>      | 0.72     | 139,248.52   | 1.103555104 | 873    | 134,152,527 |
| H <sub>2</sub> O(g) | 0.07     | 12,541.95    | 2.094515889 | 873    | 22,933,111  |
| SO <sub>2</sub>     | 0.00     | 61.10        | 3.567221307 | 873    | 190,277     |
| Total               | 1        | 192,884.14   |             |        | 197,336,297 |

Panas Sensible Output kiln

| Komponen                        | massa(kg) | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam)    |
|---------------------------------|-----------|-------------|--------|---------------|
| CO <sub>2</sub> hasil kalsinasi | 8,844.5   | 1.11833562  | 873    | 8,634,923.01  |
| O <sub>2</sub> sisa             | 2,095.2   | 1.02482896  | 873    | 1,874,536.12  |
| N <sub>2</sub> batubara         | 202.1     | 1.103555104 | 873    | 194,703.87    |
| H <sub>2</sub> O batubara       | 3,478.0   | 0.500601312 | 873    | 1,519,972.76  |
| Dust                            | 2,621.0   | 1           | 873    | 2,288,133.00  |
| Total                           | 17,240.8  |             | 873    | 14,512,268.76 |

Qloss : (H input - (ΔH produk + ΔH GHP + Hs panas keluar ))

: 1,234,182,491 - 852,175,359

: 382,007,133

Neraca Energi Kiln

| H input             |               | H output  |                  |
|---------------------|---------------|-----------|------------------|
| Hs produk preheater | 350,012,284   | Hs produk | 640,326,793.19   |
| Hs batubara         | 2,329,803     | Hs GHP    | 197336296.6      |
| Hs udara sekunder   | 147,408,908   | Hs output | 14,512,268.76    |
| Hs udara primer     | 104,749       | Q loss    | 382,007,132.75   |
| ΔHR                 | 368,165,565   |           |                  |
| H batubara          | 366,161,183   |           |                  |
| Total               | 1,234,182,491 | Total     | 1,234,182,491.34 |

Efisiensi Energi = 0.6904776  
= 69.0478 %

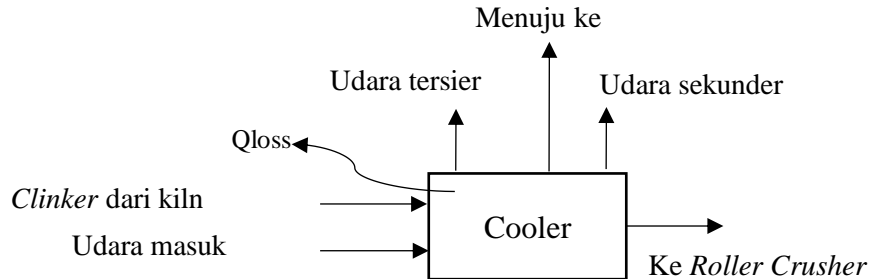
Heat Loss = 0.30952  
= 30.9522 %





## APPENDIKS NERACA ENERGI

### Cooler



Temperature bahan masuk : 1350 °C = 1623 K

Temperature reference : 25 °C = 298 K

#### Panas Sensible input klinker

| Komponen          | Batubara <15> |              | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam)     |
|-------------------|---------------|--------------|-------------|--------|----------------|
|                   | xmass         | mass(kg/jam) |             |        |                |
| C <sub>3</sub> A  | 0.0931        | 30,200.23    | 1.692946841 | 1325   | 67,743,777.71  |
| C <sub>4</sub> AF | 0.1134        | 36,785.24    | 3.493836329 | 1325   | 170,291,127.08 |
| C <sub>2</sub> S  | 0.1844        | 59,816.56    | 1.2190042   | 1325   | 96,614,548.27  |
| C <sub>3</sub> S  | 0.5805        | 188,305.39   | 1.165359891 | 1325   | 290,762,704.48 |
| Na <sub>2</sub> O | 0.0001        | 32.44        | 1.622277247 | 1325   | 69,727.08      |
| K <sub>2</sub> O  | 0.0041        | 1,329.98     | 1.476332972 | 1325   | 2,601,624.33   |
| SO <sub>3</sub>   | 0.0024        | 778.52       | 1.002107147 | 1325   | 1,033,717.36   |
| MgO               | 0.0124        | 4,022.37     | 1.320991164 | 1325   | 7,040,410.90   |
| impuritis         | 0.0097        | 3,146.53     | 1           | 1325   | 4,169,155.98   |
| Total             | 1             | 324,417.26   |             |        | 640,326,793.19 |

Temperature udara masuk : 33 °C = 306 K

Temperature reference : 25 °C = 298 K

#### Panas Sensible Udara masuk

| Komponen       | Udara masuk |              | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam)   |
|----------------|-------------|--------------|-------------|--------|--------------|
|                | xmass       | mass(kg/jam) |             |        |              |
| O <sub>2</sub> | 0.21        | 145,778.54   | 0.91625416  | 8      | 1,068,561.56 |
| N <sub>2</sub> | 0.79        | 548,404.99   | 1.023933584 | 8      | 4,492,242.27 |
| Total          | 1           | 694,183.53   |             |        | 5,560,803.82 |

#### Neraca Energi clinker keluar Cooler

Temperature clinker keluar : 121 °C = 394 K

Temperature reference : 25 °C = 298 K

Panas Sensible produk

| Komponen          | ke Roller |              | Cp(kJ/kg.K) | $\Delta T$ (K) | Hs(kJ/jam)    |
|-------------------|-----------|--------------|-------------|----------------|---------------|
|                   | xmass     | mass(kg/jam) |             |                |               |
| C <sub>3</sub> A  | 0.0931    | 30,200.23    | 0.62799108  | 96             | 1,820,685.44  |
| C <sub>4</sub> AF | 0.1134    | 36,785.24    | 3.304439609 | 96             | 11,669,241.76 |
| C <sub>2</sub> S  | 0.1844    | 59,816.56    | 0.8896322   | 96             | 5,108,615.00  |
| C <sub>3</sub> S  | 0.5805    | 188,305.39   | 0.857905621 | 96             | 15,508,632.37 |
| Na <sub>2</sub> O | 0.0001    | 32.44        | 1.217474046 | 96             | 3,791.33      |
| K <sub>2</sub> O  | 0.0041    | 1,329.98     | 0.971593818 | 96             | 124,051.03    |
| SO <sub>3</sub>   | 0.0024    | 778.52       | 0.716770859 | 96             | 53,570.21     |
| MgO               | 0.0124    | 4,022.37     | 1.037010731 | 96             | 400,439.31    |
| impuritis         | 0.0097    | 3,146.53     | 1           | 96             | 302,067.15    |
| Total             | 1.0001    | 324,384.83   |             |                | 34,991,093.59 |

Temperature udara tersier : 898 °C = 1171 K

Temperature reference : 25 °C = 298 K

Panas Sensible Udara tersier

| Komponen       | Udara tersier |              | Cp(kJ/kg.K) | $\Delta T$ (K) | Hs(kJ/jam)     |
|----------------|---------------|--------------|-------------|----------------|----------------|
|                | xmass         | mass(kg/jam) |             |                |                |
| O <sub>2</sub> | 0.21          | 24,648.00    | 1.02482896  | 873            | 22,051,964.48  |
| N <sub>2</sub> | 0.79          | 92,723.42    | 1.103555104 | 873            | 89,330,078.40  |
| Total          | 1             | 117,371.42   |             |                | 111,382,042.87 |

Temperature udara sekunder : 898 °C = 1171 K

Temperature reference : 25 °C = 298 K

Panas Sensible Udara sekunder

| Komponen       | Udara sekunder <6> |              | Cp(kJ/kg.K) | $\Delta T$ (K) | Hs(kJ/jam)     |
|----------------|--------------------|--------------|-------------|----------------|----------------|
|                | xmass              | mass(kg/jam) |             |                |                |
| O <sub>2</sub> | 0.21               | 32,620.47    | 1.02482896  | 873            | 29,184,740.38  |
| N <sub>2</sub> | 0.79               | 122,715.10   | 1.103555104 | 873            | 118,224,167.67 |
| Total          | 1                  | 155,335.57   |             |                | 147,408,908.05 |

Temperature udara ke RM : 343 °C = 616 K

Temperature reference : 25 °C = 298 K

Panas Sensible Udara ke Roller

| Komponen       | Udara ke Roller |              | Cp(kJ/kg.K) | $\Delta T$ (K) | Hs(kJ/jam)     |
|----------------|-----------------|--------------|-------------|----------------|----------------|
|                | xmass           | mass(kg/jam) |             |                |                |
| O <sub>2</sub> | 0.21            | 88,510.07    | 0.95516536  | 318            | 26,884,278.54  |
| N <sub>2</sub> | 0.79            | 332,966.47   | 1.052468464 | 318            | 111,438,872.80 |
| Total          | 1               | 421,476.54   |             |                | 138,323,151.35 |

Temperature debu ke EP : 228 °C = 501 K

Temperature reference : 25 °C = 298 K

Panas Sensible Debu ke EP

| Komponen | Udara sekunder <6> |              | Cp(kJ/kg.K) | ΔT (K) | Hs(kJ/jam) |
|----------|--------------------|--------------|-------------|--------|------------|
|          | xmass              | mass(kg/jam) |             |        |            |
| Ash      | 0.21               | 9.73         | 1           | 203    | 1,975.50   |

Qloss : (ΣHs input -( ΣHs ioutput ))  
 : 645,887,597 - 432,105,196  
 : 213,782,401

Neraca Energi Cooler

| H input          |                | H output          |                |
|------------------|----------------|-------------------|----------------|
| Hs input klinker | 640,326,793.19 | Hs produk         | 34,991,093.59  |
| Hs udara masuk   | 5,560,803.82   | Hs udara tersier  | 111382042.9    |
|                  |                | Hs udara sekunder | 147,408,908.05 |
|                  |                | Hs udara ke RM    | 138,323,151.35 |
|                  |                | Q loss            | 213,782,401.15 |
| Total            | 645,887,597.01 | Total             | 645,887,597.01 |



**LAMPIRAN C**  
**NERACA ENTALPI, ENTROPI, EKSERGI RKC 4**

| Komponen                        | BM   |
|---------------------------------|------|
| CaCO <sub>3</sub>               | 100  |
| CaO                             | 56   |
| CO <sub>2</sub>                 | 44   |
| C <sub>2</sub> S                | 172  |
| C <sub>3</sub> S                | 228  |
| C <sub>3</sub> A                | 270  |
| C <sub>4</sub> AF               | 486  |
| SiO <sub>2</sub>                | 60   |
| Al <sub>2</sub> O <sub>3</sub>  | 102  |
| Fe <sub>2</sub> O <sub>3</sub>  | 160  |
| MgO                             | 40.3 |
| K <sub>2</sub> O                | 55   |
| Na <sub>2</sub> O               | 62   |
| SO <sub>3</sub>                 | 80   |
| impuritis                       | 1    |
| H <sub>2</sub> O <sub>(l)</sub> | 18   |
| H <sub>2</sub> O <sub>(g)</sub> | 18   |
| C                               | 12   |
| H                               | 1    |
| N                               | 14   |
| O                               | 16   |
| S                               | 32   |

| Komponen                        | Standard Chemical Exergy (kJ/mol) |
|---------------------------------|-----------------------------------|
| CaCO <sub>3</sub>               | 16300                             |
| CaO                             | 127300                            |
| CO <sub>2</sub>                 | 19480                             |
| C <sub>2</sub> S                | 129900                            |
| C <sub>3</sub> S                | 40700                             |
| C <sub>3</sub> A                | 382600                            |
| C <sub>4</sub> AF               | 212200                            |
| SiO <sub>2</sub>                | 8200                              |
| Al <sub>2</sub> O <sub>3</sub>  | 200460                            |
| Fe <sub>2</sub> O <sub>3</sub>  | 16500                             |
| MgO                             | 59100                             |
| K <sub>2</sub> O                | 413100                            |
| Na <sub>2</sub> O               | 296200                            |
| SO <sub>3</sub>                 | 249100                            |
| impuritis                       | 1000                              |
| H <sub>2</sub> O <sub>(l)</sub> | 900                               |
| H <sub>2</sub> O <sub>(g)</sub> | 9500                              |
| C                               | 409870                            |
| H                               | 331300                            |
| N                               | 720                               |
| O                               | 2233700                           |

|                 |    |
|-----------------|----|
| NO <sub>2</sub> | 46 |
| SO <sub>2</sub> | 64 |
| O <sub>2</sub>  | 32 |
| N <sub>2</sub>  | 28 |

|                 |        |
|-----------------|--------|
| S               | 609600 |
| NO <sub>2</sub> | 55600  |
| SO <sub>2</sub> | 313400 |
| O <sub>2</sub>  | 3970   |
| N <sub>2</sub>  | 690    |

**Stream Inlet  
Produk Preheater**

| Komponen                       | produk preheater |               | Cp(kJ/kg.K) | ΔT(K) | T(K) | T <sub>ref</sub> (K) | Hs(kJ/jam)  | ΔS(kJ/kg.K) | E <sup>PH</sup> (kJ/jam) | E <sup>CH</sup> (kJ/jam) |
|--------------------------------|------------------|---------------|-------------|-------|------|----------------------|-------------|-------------|--------------------------|--------------------------|
|                                | xmass            | mass (kg/jam) |             |       |      |                      |             |             |                          |                          |
| SiO <sub>2</sub>               | 0.19724          | 66024         | 1.2135221   | 875   | 1623 | 298                  | 70,106,387  | 135,801.1   | 29,637,651.5             | 9,023,280                |
| Al <sub>2</sub> O <sub>3</sub> | 0.05556          | 18598         | 1.3218438   | 875   | 1623 | 298                  | 21,510,232  | 41,666.9    | 9,093,504.9              | 36,549,754               |
| Fe <sub>2</sub> O <sub>3</sub> | 0.03689          | 12348         | 1.1304563   | 875   | 1623 | 298                  | 12,214,015  | 23,659.4    | 5,163,505.5              | 1,273,388                |
| CaCO <sub>3</sub> sisa         | 0.05781          | 19351         | 1.3976758   | 875   | 1623 | 298                  | 23,665,719  | 45,842.2    | 10,004,742.1             | 3,154,226                |
| MgCO <sub>3</sub> sisa         | 0.00188          | 630           | 0.2785638   | 875   | 1623 | 298                  | 153,558     | 297.5       | 64,917.2                 | -                        |
| CaO                            | 0.61508          | 205895        | 1.165511    | 875   | 1623 | 298                  | 209,976,778 | 406,740.2   | 88,768,211.2             | 468,044,572              |
| MgO                            | 0.01703          | 5700          | 1.2575484   | 875   | 1623 | 298                  | 6,272,023   | 12,149.4    | 2,651,513.4              | 8,359,057                |
| SO <sub>3</sub>                | 0.0012           | 403           | 0.9714403   | 875   | 1623 | 298                  | 342,724     | 663.9       | 144,887.5                | 1,255,464                |
| Na <sub>2</sub> O              | 0.00181          | 605           | 1.5691621   | 875   | 1623 | 298                  | 830,401     | 1,608.5     | 351,053.9                | 2,889,383                |
| K <sub>2</sub> O               | 0.00482          | 1613          | 1.2819912   | 875   | 1623 | 298                  | 1,809,146   | 3,504.4     | 764,821.0                | 12,113,594               |
| Cl                             | 0                | 0             | 0           | 875   | 1623 | 298                  | -           | -           | -                        | -                        |
| impuritis                      | 0.00843          | 2822          | 1           | 875   | 1623 | 298                  | 2,469,600   | 4,783.8     | 1,044,029.6              | 2,822,400                |
| Ash                            | 0.00226          | 756           | 1           | 875   | 1623 | 298                  | 661,701     | 1,281.8     | 279,735.9                | 756,230                  |
| Total                          | 1                | 334746        |             |       |      |                      | 350,012,284 | 677,999.0   | 147,968,574              | 546,241,348              |

### BATUBARA

| Komponen                        | Batubara |               | Cp(kJ/kg.K) | $\Delta T(K)$ | T(K) | T <sub>ref</sub> (K) | Hs(kJ/jam)   | $\Delta S(kJ/kg.K)$ | E <sup>PH</sup> (kJ/jam) | E <sup>CH</sup> (kJ/jam) |
|---------------------------------|----------|---------------|-------------|---------------|------|----------------------|--------------|---------------------|--------------------------|--------------------------|
|                                 | xmass    | mass (kg/jam) |             |               |      |                      |              |                     |                          |                          |
| C                               | 0.4762   | 11,190.70     | 0.8990      | 45            | 343  | 298                  | 452,695.99   | 1,414.80            | 31,086.99                | 382,227,684              |
| H <sub>2</sub>                  | 0.0593   | 1,393.55      | 14.4305     | 45            | 343  | 298                  | 904,933.96   | 2,828.16            | 62,142.53                | 461,683,115              |
| N <sub>2</sub>                  | 0.0086   | 202.10        | 1.0273      | 45            | 343  | 298                  | 9,343.14     | 29.20               | 641.60                   | 4,980                    |
| O <sub>2</sub>                  | 0.2596   | 6,100.60      | 0.9209      | 45            | 343  | 298                  | 252,811.48   | 790.10              | 17,360.76                | 756,856                  |
| S                               | 0.0013   | 30.55         | 0.7618      | 45            | 343  | 298                  | 1,047.24     | 3.27                | 71.92                    | 581,978                  |
| H <sub>2</sub> O <sub>(l)</sub> | 0.148    | 3,478.00      | 4.2123      | 45            | 343  | 298                  | 659,268.26   | 2,060.39            | 45,272.47                | 173,900                  |
| Ash                             | 0.047    | 1,104.50      | 1.0000      | 45            | 343  | 298                  | 49,702.50    | 155.33              | 3,413.11                 | 1,104,500                |
| Total                           | 1        | 23,500.00     |             |               |      |                      | 2,329,802.56 | 7,281.25            | 159,989.39               | 846,533,013              |

### Udara Sekunder

| Komponen       | Udara Sekunder |               | Cp(kJ/kg.K) | $\Delta T(K)$ | T(K) | T <sub>ref</sub> (K) | Hs(kJ/jam)  | $\Delta S(kJ/kg.K)$ | E <sup>PH</sup> (kJ/jam) | E <sup>CH</sup> (kJ/jam) |
|----------------|----------------|---------------|-------------|---------------|------|----------------------|-------------|---------------------|--------------------------|--------------------------|
|                | xmass          | mass (kg/jam) |             |               |      |                      |             |                     |                          |                          |
| O <sub>2</sub> | 0.21           | 32,620.47     | 1.0248      | 873           | 1171 | 298                  | 29,184,740  | 45,750.17           | 15,551,190               | 4,046,976.94             |
| N <sub>2</sub> | 0.79           | 122,715.10    | 1.1036      | 873           | 1171 | 298                  | 118,224,168 | 185,328.9           | 62,996,158               | 3,024,050.62             |
| Total          | 1.00           | 155,335.57    |             |               |      |                      | 147,408,908 | 231,079.1           | 78,547,348               | 7,071,027.56             |

### Udara Primer

| Komponen       | Udara Primer |               | Cp(kJ/kg.K) | $\Delta T(K)$ | T(K) | T <sub>ref</sub> (K) | Hs(kJ/jam) | $\Delta S(kJ/kg.K)$ | E <sup>PH</sup> (kJ/jam) | E <sup>CH</sup> (kJ/jam) |
|----------------|--------------|---------------|-------------|---------------|------|----------------------|------------|---------------------|--------------------------|--------------------------|
|                | xmass        | mass (kg/jam) |             |               |      |                      |            |                     |                          |                          |
| O <sub>2</sub> | 0.21         | 4,394.96      | 0.9158776   | 5             | 303  | 298                  | 20,126.23  | 66.98               | 166.98                   | 545,249.80               |
| N <sub>2</sub> | 0.79         | 16,533.42     | 1.0236574   | 5             | 303  | 298                  | 84,622.81  | 281.61              | 702.08                   | 407,430.79               |
| Total          | 1.00         | 20,928.38     |             |               |      |                      | 104,749.04 | 348.59              | 869.06                   | 952,680.59               |

### Steam Outlet

#### Produk kiln

| Komponen          | Produk kiln |               | Cp(kJ/kg.K) | $\Delta T(K)$ | T(K) | T <sub>ref</sub> (K) | Hs(kJ/jam)  | $\Delta S(kJ/kg.K)$ | E <sup>PH</sup> (kJ/jam) | E <sup>CH</sup> (kJ/jam) |
|-------------------|-------------|---------------|-------------|---------------|------|----------------------|-------------|---------------------|--------------------------|--------------------------|
|                   | xmass       | mass (kg/jam) |             |               |      |                      |             |                     |                          |                          |
| C <sub>3</sub> A  | 0.0931      | 30,200.23     | 1.6929468   | 1325          | 1623 | 298                  | 67,743,778  | 86,657.7            | 41,919,770               | 42,794,841               |
| C <sub>4</sub> AF | 0.1134      | 36,785.24     | 3.4938363   | 1325          | 1623 | 298                  | 170,291,127 | 217,836.2           | 105,375,950              | 16,061,374               |
| C <sub>2</sub> S  | 0.1844      | 59,816.56     | 1.2190042   | 1325          | 1623 | 298                  | 96,614,548  | 123,589.2           | 59,784,970               | 45,175,415               |
| C <sub>3</sub> S  | 0.5805      | 188,305.39    | 1.1653599   | 1325          | 1623 | 298                  | 290,762,704 | 371,943.2           | 179,923,622              | 33,614,164               |
| Na <sub>2</sub> O | 0.0001      | 32.44         | 1.6222772   | 1325          | 1623 | 298                  | 69,727      | 89.2                | 43,147                   | 154,972                  |
| K <sub>2</sub> O  | 0.0041      | 1,329.98      | 1.476333    | 1325          | 1623 | 298                  | 2,601,624   | 3,328.0             | 1,609,882                | 9,989,342                |
| SO <sub>3</sub>   | 0.0024      | 778.52        | 1.0021071   | 1325          | 1623 | 298                  | 1,033,717   | 1,322.3             | 639,663                  | 2,424,128                |
| MgO               | 0.0124      | 4,022.37      | 1.3209912   | 1325          | 1623 | 298                  | 7,040,411   | 9,006.1             | 4,356,598                | 5,898,813                |
| impuritis         | 0.0097      | 3,146.53      | 1           | 1325          | 1623 | 298                  | 4,169,156   | 5,333.2             | 2,579,869                | 3,146,533                |
| Total             | 1.0001      | 324,417.26    |             |               |      |                      | 640,326,793 | 819,105.1           | 396,233,471              | 159,259,582              |

#### Panas Sensibel GHP

| Komponen                        | Panas Sensibel GHP |               | Cp(kJ/kg.K) | $\Delta T(K)$ | T(K) | T <sub>ref</sub> (K) | Hs(kJ/jam)  | $\Delta S(kJ/kg.K)$ | E <sup>PH</sup> (kJ/jam) | E <sup>CH</sup> (kJ/jam) |
|---------------------------------|--------------------|---------------|-------------|---------------|------|----------------------|-------------|---------------------|--------------------------|--------------------------|
|                                 | xmass              | mass (kg/jam) |             |               |      |                      |             |                     |                          |                          |
| CO <sub>2</sub>                 | 0.21               | 41,032.57     | 1.1183356   | 873           | 1171 | 298                  | 40,060,382  | 62,798.9            | 21,346,313               | 18,166,236.3             |
| N <sub>2</sub>                  | 0.72               | 139,248.52    | 1.1035551   | 873           | 1171 | 298                  | 134,152,527 | 210,298.3           | 71,483,639               | 3,431,481.4              |
| H <sub>2</sub> O <sub>(g)</sub> | 0.07               | 12,541.95     | 2.0945159   | 873           | 1171 | 298                  | 22,933,111  | 35,950.1            | 12,219,988               | 6,619,362.5              |
| SO <sub>2</sub>                 | 0.00               | 61.10         | 3.5672213   | 873           | 1171 | 298                  | 190,277     | 298.3               | 101,390                  | 299,199.1                |
| Total                           | 1.00               | 192,884.14    |             |               |      |                      | 197,336,297 | 309,345.5           | 105,151,330              | 28,516,279.3             |

**Panas Sensibel Output Kiln**

| Komponen                        | massa(kg) | Cp(kJ/kg.K) | $\Delta T(K)$ | T(K) | $T_{ref}(K)$ | Hs(kJ/jam)   | $\Delta S(kJ/kg.K)$ | $E^{PH}(kJ/jam)$ | $E^{CH}(kJ/jam)$ |
|---------------------------------|-----------|-------------|---------------|------|--------------|--------------|---------------------|------------------|------------------|
| CO <sub>2</sub> hasil kalsinasi | 8,844.48  | 1.1183356   | 873           | 1171 | 298          | 8,634,923.0  | 13,536.16           | 4,601,148.66     | 3,915,690.38     |
| O <sub>2</sub> sisa             | 2,095.21  | 1.024829    | 873           | 1171 | 298          | 1,874,536.1  | 2,938.53            | 998,853.07       | 259,937.36       |
| N <sub>2</sub> batubara         | 202.10    | 1.1035551   | 873           | 1171 | 298          | 194,703.9    | 305.22              | 103,748.63       | 4,980.32         |
| H <sub>2</sub> O batubara       | 3,478.00  | 0.5006013   | 873           | 1171 | 298          | 1,519,972.8  | 2,382.72            | 809,922.75       | 173,900.00       |
| Dust                            | 2,621.00  | 1           | 873           | 1171 | 298          | 2,288,133.0  | 3,586.89            | 1,219,239.60     | 2,621,000.00     |
| Total                           | 17,240.79 |             |               |      |              | 14,512,268.8 | 22,749.52           | 7,732,912.72     | 6,975,508.07     |

$$\Sigma EX_{in} - \Sigma EX_{out} = \Sigma EX_{dest}$$

$$\Psi = (h-h_o) - T_o (S-S_o)$$

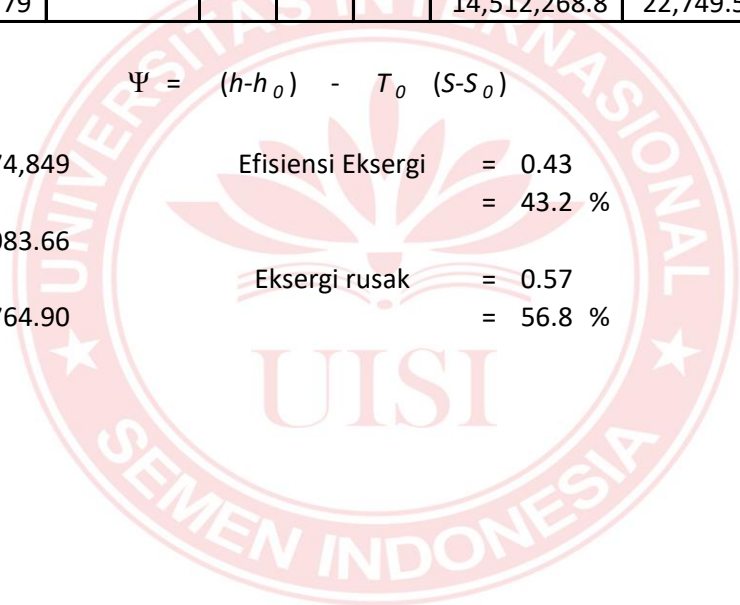
$$\Sigma [Ex_{in}] = 1,627,474,849$$

$$\begin{aligned} \text{Efisiensi Eksergi} &= 0.43 \\ &= 43.2 \% \end{aligned}$$

$$\Sigma [Ex_{out}] = 703,869,083.66$$

$$\begin{aligned} \text{Eksergi rusak} &= 0.57 \\ &= 56.8 \% \end{aligned}$$

$$\Sigma [Ex_{dest}] = 923,605,764.90$$

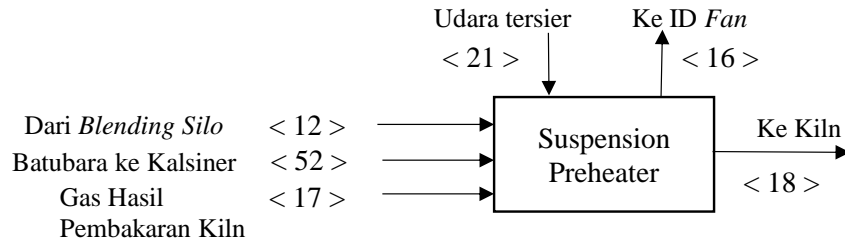








**LAMPIRAN D**  
**APPENDIKS NERACA MASSA DAN NERACA ENERGI SP RKC 2**  
**Neraca Massa**



Keterangan :

Fungsi Suspension Preheater = Berfungsi untuk proses pemanasan awal dan proses pre-kalsinasi sebesar 89%

Udara Tersier = Udara panas dari Cooler yang digunakan kembali untuk udara pembakaran di kalsiner

Basis = 1 jam operasi

Total Kiln Feed = 517.1 ton/jam = 517,073.0 kg/jam

Komposisi Umpan Masuk Suspension Preheater

| No    | Komponen                       | Input  |               |
|-------|--------------------------------|--------|---------------|
|       |                                | xmass  | mass (kg/jam) |
| 1     | CaCO <sub>3</sub>              | 0.7277 | 376,249.42    |
| 2     | CaO                            | 0.0403 | 20,838.43     |
| 3     | Fe <sub>2</sub> O <sub>3</sub> | 0.0254 | 13,132.75     |
| 4     | SiO <sub>2</sub>               | 0.1477 | 76,393.63     |
| 5     | Al <sub>2</sub> O <sub>3</sub> | 0.0401 | 20,744.69     |
| 6     | MgO                            | 0.0084 | 4,362.19      |
| 7     | K <sub>2</sub> O               | 0.0028 | 1,448.88      |
| 8     | Na <sub>2</sub> O              | 0.0001 | 43.99         |
| 9     | SO <sub>3</sub>                | 0.0017 | 853.85        |
| 10    | impuritis                      | 0.0036 | 1,878.25      |
| 11    | H <sub>2</sub> O               | 0.0022 | 1,126.95      |
| Total |                                | 1.00   | 517,073.03    |

BM masing-masing senyawa :

CaCO<sub>3</sub> = 100

CaO = 56

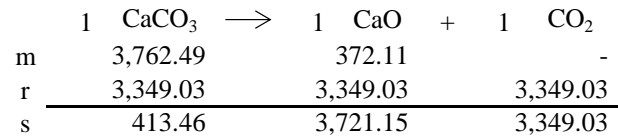
CO<sub>2</sub> = 44

mol CaCO<sub>3</sub> yang masuk = 3,762.49 kmol/jam

mol CaCO<sub>3</sub> bereaksi = 89% x 3,762.49

$$\begin{aligned} &= 3,349.03 \text{ kmol/jam} \\ \text{mol CaO mula- mula} &= 372.11 \text{ kmol/jam} \end{aligned}$$

Reaksi Kalsinasi :



$$\begin{aligned} \text{massa CaCO}_3 \text{ tersisa} &= \text{BM} \times \text{mol} \\ &= 41,346.09 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} \text{massa CaO terbentuk} &= \text{BM} \times \text{mol} \\ &= 208,384.29 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} \text{massa CO}_2 \text{ terbentuk} &= \text{BM} \times \text{mol} \\ &= 147,357.46 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} \text{Net Calorific Value} &= 4504 \text{ kkal/kg batubara} \\ \text{dari batubara} & \end{aligned}$$

$$\text{Total kebutuhan batubara} = 46,875 \text{ kg/jam}$$

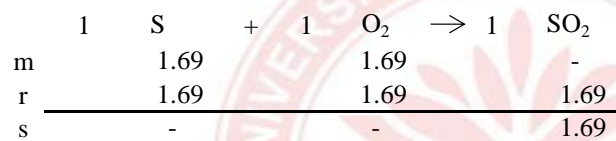
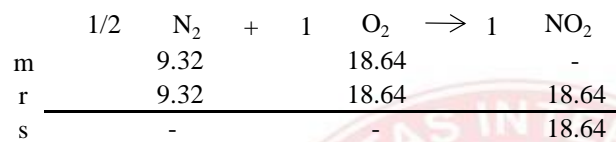
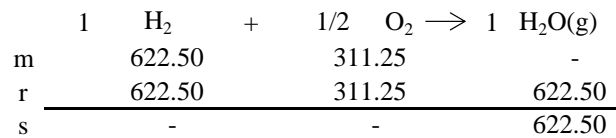
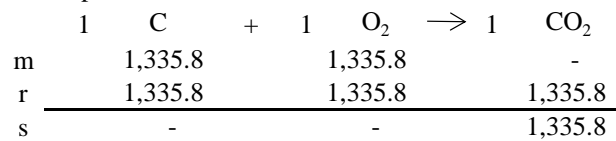
$$\begin{aligned} \text{Kebutuhan batubara di} &= 30,000 \text{ kg/jam} \\ \text{kalsiner} & \end{aligned}$$

| Komposisi Batubara |         |                   |
|--------------------|---------|-------------------|
| Komponen           | % berat | Massrate (kg/jam) |
| C                  | 53.43   | 16,029            |
| H                  | 4.15    | 1,245             |
| N                  | 0.87    | 261               |
| O                  | 23.24   | 6,972             |
| S                  | 0.18    | 54                |
| H <sub>2</sub> O   | 14.88   | 4,464             |
| Ash                | 3.25    | 975               |
| Total              | 100.00  | 30,000            |

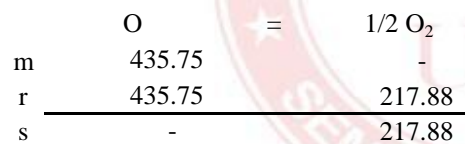
BM masing-masing unsur kandungan batubara :

|        |                       |
|--------|-----------------------|
| C = 12 | CO <sub>2</sub> = 44  |
| H = 1  | H <sub>2</sub> O = 18 |
| N = 14 | NO <sub>2</sub> = 46  |
| O = 16 | SO <sub>2</sub> = 64  |
| S = 32 |                       |

Reaksi pembakaran batubara :



Kadar O<sub>2</sub> yang terkandung dalam batubara :



$$\text{Kebutuhan O}_2 \text{ utk pembakaran} = 1,335.75 + 311.25 + 18.6 + 1.69$$

$$= 1,667.33 \text{ kmol/jam}$$

$$= 53,354.6 \text{ kg/jam}$$

$$\text{O}_2 \text{ dalam batubara} = 6,972.00 \text{ kg/jam}$$

$$\text{Kebutuhan O}_2 \text{ scr stoikiometris} = 53,354.57 - 6,972.00$$

$$= 46,382.57 \text{ kg/jam}$$

$$\text{Kebutuhan O}_2 + \text{O}_2 \text{ ekkses} = 47,542.14 \text{ kg/jam}$$

$$(\text{asumsi udara ekkses} = 2.5\%)$$

(FLSmidth Institute)

| Perhitungan Fraksi Massa Udara |            |    |              |
|--------------------------------|------------|----|--------------|
| Komponen                       | Fraksi mol | BM | Fraksi massa |
| O <sub>2</sub>                 | 0.21       | 32 | 0.23         |
| N <sub>2</sub>                 | 0.79       | 28 | 0.77         |
| Total                          | 1.00       |    | 1.00         |

$$\begin{aligned} \text{Total udara stoikiometris} &= \frac{100}{23} \times 47,542.14 \\ + \text{udara eksek} &= 204,035 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} \text{Udara dari conveying} &= 0.25 \frac{\text{kg udara}}{\text{kg batubara}} \times 30,000 \\ \text{batubara} &= 7,500 \text{ kg/jam} \end{aligned}$$

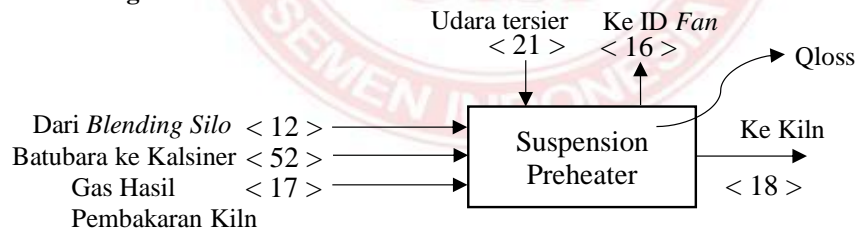
$$\begin{aligned} \text{Udara} &= \text{Kebutuhan udara pembakaran} - \text{Udara conveying batu bara} \\ \text{tersier} &= 204,035 - 7,500 \\ &= 196,535 \text{ kg/jam} \end{aligned}$$

| Input                          |                                  |               | Output                         |                                |               |
|--------------------------------|----------------------------------|---------------|--------------------------------|--------------------------------|---------------|
| Komponen                       | < 12 > dari <i>blending silo</i> |               | Komponen                       | < 18 > menuju ke kiln          |               |
|                                | xmass                            | mass (kg/jam) |                                | xmass                          | mass (kg/jam) |
| CaCO <sub>3</sub>              | 0.7277                           | 376,249.42    | CaCO <sub>3</sub>              | 0.1119                         | 41,346.09     |
| CaO                            | 0.0403                           | 20,838.43     | CaO                            | 0.5639                         | 208,384.29    |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0254                           | 13,132.75     | Fe <sub>2</sub> O <sub>3</sub> | 0.0355                         | 13,132.75     |
| SiO <sub>2</sub>               | 0.1477                           | 76,393.63     | SiO <sub>2</sub>               | 0.2067                         | 76,393.63     |
| Al <sub>2</sub> O <sub>3</sub> | 0.0401                           | 20,744.69     | Al <sub>2</sub> O <sub>3</sub> | 0.0561                         | 20,744.69     |
| MgO                            | 0.0084                           | 4,362.19      | MgO                            | 0.0118                         | 4,362.19      |
| K <sub>2</sub> O               | 0.0028                           | 1,448.88      | K <sub>2</sub> O               | 0.0039                         | 1,448.88      |
| Na <sub>2</sub> O              | 0.0001                           | 43.99         | Na <sub>2</sub> O              | 0.0001                         | 43.99         |
| SO <sub>3</sub>                | 0.0017                           | 853.85        | SO <sub>3</sub>                | 0.0023                         | 853.85        |
| impuritis                      | 0.0036                           | 1,878.25      | impuritis                      | 0.0064                         | 2,381.18      |
| H <sub>2</sub> O               | 0.0022                           | 1,126.95      | H <sub>2</sub> O               | 0.0013                         | 472.07        |
| Total                          | 1.00                             | 517,073.03    | Total                          | 1.00                           | 369,563.61    |
| Input                          |                                  |               | Output                         |                                |               |
| Komponen                       | < 17 > gas pembakaran kiln       |               | Komponen                       | < 16 > menuju ke ID <i>Fan</i> |               |
|                                | xmass                            | mass (kg/jam) |                                | xmass                          | mass (kg/jam) |
| CO <sub>2</sub>                | 0.3433                           | 51,252.1      | CO <sub>2</sub>                | 0.4849                         | 257,382.6     |
| H <sub>2</sub> O(g)            | 0.0590                           | 8,813.8       | H <sub>2</sub> O(g)            | 0.0482                         | 25,609.76     |
| NO <sub>2</sub>                | 0.0032                           | 482.4         | NO <sub>2</sub>                | 0.0025                         | 1,339.96      |
| O <sub>2</sub>                 | 0.0044                           | 652.25        | O <sub>2</sub>                 | 0.0034                         | 1,811.82      |
| N <sub>2</sub>                 | 0.5896                           | 88,027.24     | N <sub>2</sub>                 | 0.4606                         | 244,520.1     |
| SO <sub>2</sub>                | 0.0004                           | 60.750        | SO <sub>2</sub>                | 0.0003                         | 168.750       |
| Total                          | 1.00                             | 149,289       | Total                          | 1.00                           | 530,832.9     |
| Input                          |                                  |               |                                |                                |               |

| Komponen            | < 21 > udara tersier        |               |
|---------------------|-----------------------------|---------------|
|                     | xmass                       | mass (kg/jam) |
| O <sub>2</sub>      | 0.2330                      | 45,794.56     |
| N <sub>2</sub>      | 0.7670                      | 150,740.44    |
| Total               | 1.00                        | 196,535.00    |
| Input               |                             |               |
| Komponen            | < 52 > batubara ke kalsiner |               |
|                     | xmass                       | mass (kg/jam) |
| C                   | 0.5343                      | 16,029        |
| H                   | 0.0415                      | 1,245         |
| N                   | 0.0087                      | 261           |
| O                   | 0.2324                      | 6,972         |
| S                   | 0.0018                      | 54            |
| H <sub>2</sub> O(l) | 0.1488                      | 4,464         |
| Ash                 | 0.0325                      | 975           |
| Total               | 1.00                        | 30,000        |
| Input               |                             |               |
| Komponen            | < 52 > udara masuk          |               |
|                     | xmass                       | mass (kg/jam) |
| O <sub>2</sub>      | 0.2330                      | 1,747.57      |
| N <sub>2</sub>      | 0.7670                      | 5,752.43      |
| Total               | 1.00                        | 7,500.00      |
|                     |                             | 900,396.556   |

(0.0) (0.0)

### Neraca Energi



» Neraca energi dari Blending Silo :

temperatur feed = 50 °C = 323 K  
 temperatur reference = 25 °C = 298 K

### Panas Sensibel Raw Meal

| Komponen                       | < 12 > Blending Silo |               | Cp (kJ/kg.K) | ΔT (K) | Hs (kJ/jam)  |
|--------------------------------|----------------------|---------------|--------------|--------|--------------|
|                                | xmass                | mass (kg/jam) |              |        |              |
| CaCO <sub>3</sub>              | 0.7277               | 376,249.42    | 0.861        | 25     | 8,098,063.50 |
| CaO                            | 0.0403               | 20,838.43     | 0.787        | 25     | 409,853.93   |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0254               | 13,132.75     | 0.676        | 25     | 221,925.31   |
| SiO <sub>2</sub>               | 0.1477               | 76,393.63     | 0.793        | 25     | 1,514,983.97 |
| Al <sub>2</sub> O <sub>3</sub> | 0.0401               | 20,744.69     | 0.819        | 25     | 424,946.33   |

|                     |        |            |       |    |              |
|---------------------|--------|------------|-------|----|--------------|
| MgO                 | 0.0084 | 4,362.19   | 0.960 | 25 | 104,710.73   |
| K <sub>2</sub> O    | 0.0028 | 1,448.88   | 0.924 | 25 | 33,463.45    |
| Na <sub>2</sub> O   | 0.0001 | 43.99      | 1.142 | 25 | 1,256.11     |
| SO <sub>3</sub>     | 0.0017 | 853.85     | 0.657 | 25 | 14,023.56    |
| impuritis           | 0.0036 | 1,878.25   | 1.000 | 25 | 46,956.35    |
| H <sub>2</sub> O(l) | 0.0022 | 1,126.95   | 4.202 | 25 | 118,382.65   |
| Total               | 1.00   | 517,073.03 |       |    | 10,988,565.9 |

- » Panas sensibel udara tersier (range suhu = 790 - 830 °C)  
 temperatur udara tersier = 810 °C = 1083 K  
 temperatur reference = 25 °C = 298 K

#### Panas Sensibel Udara Tersier

| Komponen       | < 21 > Udara tersier |               | Cp (kJ/kg.K) | ΔT (K) | Hs (kJ/jam) |
|----------------|----------------------|---------------|--------------|--------|-------------|
|                | xmass                | mass (kg/jam) |              |        |             |
| O <sub>2</sub> | 0.2330               | 45,794.56     | 1.0376       | 785    | 37,301,513  |
| N <sub>2</sub> | 0.7670               | 150,740.44    | 1.1129       | 785    | 131,695,901 |
| Total          | 1.00                 | 196,535.00    |              |        | 168,997,414 |

- » Panas sensibel batubara (range suhu = 57 - 70 °C)  
 temperatur batubara = 60 °C = 333 K  
 temperatur reference = 25 °C = 298 K

#### Panas Sensibel Batubara

| Komponen            | < 52 > Batubara |               | Cp (kJ/kg.K) | ΔT (K) | Hs (kJ/jam)  |
|---------------------|-----------------|---------------|--------------|--------|--------------|
|                     | xmass           | mass (kg/jam) |              |        |              |
| C                   | 0.5343          | 16,029        | 0.8365       | 35     | 469,306.16   |
| H                   | 0.0415          | 1,245         | 14.397       | 35     | 313,666.10   |
| N                   | 0.0087          | 261           | 1.0255       | 35     | 4,683.96     |
| O                   | 0.2324          | 6,972         | 0.9184       | 35     | 112,052.40   |
| S                   | 0.0018          | 54            | 0.7450       | 35     | 1,408.11     |
| H <sub>2</sub> O(l) | 0.1488          | 4,464         | 4.2019       | 35     | 656,499.90   |
| Ash                 | 0.0325          | 975           | 1.00         | 35     | 34,125.00    |
| Total               | 1.00            | 30,000        |              |        | 1,591,741.63 |
| Komponen            | < 52 > Batubara |               | Cp (kJ/kg.K) | ΔT (K) | Hs (kJ/jam)  |
|                     | xmass           | mass (kg/jam) |              |        |              |
| O <sub>2</sub>      | 0.2330          | 1,747.57      | 0.9184       | 35     | 56,173.18    |
| N <sub>2</sub>      | 0.7670          | 5,752.43      | 1.0255       | 35     | 206,468.44   |
| Total               | 1.00            | 7,500.00      |              |        | 262,641.63   |
| Total               |                 |               |              |        | 1,854,383.26 |

- » Neraca energi pembakaran batubara  
 Massa batubara = 30,000 kg/jam  
 Heating value = 4,504 kkal/kg



$$\begin{aligned}
 H \text{ batubara} &= 30,000 \times 4,504 \\
 &= 135,120,000 \text{ kkal/jam} \\
 &= 565,720,416 \text{ kJ/jam}
 \end{aligned}$$

» Panas sensibel gas dari kiln

$$\text{temperatur gas dari kiln} = 1000 \text{ }^\circ\text{C} = 1273 \text{ K}$$

$$\text{temperatur reference} = 25 \text{ }^\circ\text{C} = 298 \text{ K}$$

#### Panas Sensibel Gas dari Kiln

| Komponen            | < 17 > Gas dari Kiln |               | Cp (kJ/kg.K) | $\Delta T$ (K) | Hs (kJ/jam)  |
|---------------------|----------------------|---------------|--------------|----------------|--------------|
|                     | xmass                | mass (kg/jam) |              |                |              |
| CO <sub>2</sub>     | 0.3433               | 51,252.09     | 1.1339       | 975            | 56,660,016.9 |
| H <sub>2</sub> O(g) | 0.0590               | 8,813.81      | 2.1338       | 975            | 18,337,063.8 |
| NO <sub>2</sub>     | 0.0032               | 482.38        | 1.1666       | 975            | 548,675.8    |
| O <sub>2</sub>      | 0.0044               | 652.25        | 1.0376       | 975            | 659,879.8    |
| N <sub>2</sub>      | 0.5896               | 88,027.24     | 1.1129       | 975            | 95,520,044   |
| SO <sub>2</sub>     | 0.0004               | 60.75         | 0.8647       | 975            | 51,216.0     |
| Total               | 1.00                 | 149,288.53    |              |                | 171,776,896  |

» Panas sensibel gas keluar preheater (range suhu = 385 - 400 °C)

$$\text{temperatur gas keluar preheater} = 390 \text{ }^\circ\text{C} = 663 \text{ K}$$

$$\text{temperatur reference} = 25 \text{ }^\circ\text{C} = 298 \text{ K}$$

#### Panas Sensibel Gas Keluar Preheater

| Komponen            | < 16 > ke ID Fan |               | Cp (kJ/kg.K) | $\Delta T$ (K) | Hs (kJ/jam)  |
|---------------------|------------------|---------------|--------------|----------------|--------------|
|                     | xmass            | mass (kg/jam) |              |                |              |
| CO <sub>2</sub>     | 0.4849           | 257,382.56    | 0.9708       | 365            | 91,203,601.7 |
| H <sub>2</sub> O(g) | 0.0482           | 25,609.76     | 1.9250       | 365            | 17,993,805.0 |
| NO <sub>2</sub>     | 0.0025           | 1,339.96      | 0.9982       | 365            | 488,188.3    |
| O <sub>2</sub>      | 0.0034           | 1,811.82      | 0.9560       | 365            | 632,244.6    |
| N <sub>2</sub>      | 0.4606           | 244,520.10    | 1.0531       | 365            | 93,990,041.1 |
| SO <sub>2</sub>     | 0.0003           | 168.75        | 0.7712       | 365            | 47,502.5     |
| Total               | 1.00             | 530,832.94    |              |                | 204,355,383  |

» Panas **latent** penguapan air pada 50 °C      Hv 2592.1 kJ/kg

$$\lambda = 2,382.77 \text{ kJ/kg} \quad \text{HI} 209.33 \text{ kJ/kg}$$

$$\text{HI} = m \times \lambda$$

$$= 5,590.95 \times 2,382.77$$

$$= 13,321,953.85 \text{ kJ/jam}$$

» Neraca energi reaksi kalsinasi :

$$\text{temperatur reaktan} = 780 \text{ }^\circ\text{C} = 1053 \text{ K}$$

$$\text{temperatur produk} = 850 \text{ }^\circ\text{C} = 1123 \text{ K}$$

|   |   |                   |   |   |         |   |   |                 |
|---|---|-------------------|---|---|---------|---|---|-----------------|
|   | 1 | CaCO <sub>3</sub> | → | 1 | CaO     | + | 1 | CO <sub>2</sub> |
| m |   | 3,762.49          |   |   | 372.1   |   |   | -               |
| r |   | 3,349.03          |   |   | 3,349.0 |   |   | 3,349.03        |
| s |   | 413.46            |   |   | 3,721.1 |   |   | 3,349.03        |

Data heat of formation pada 25 °C (  $\Delta H_{f,298}$  ) :

Tabel Heat of Formation H.Allaboun

| Komponen   | $\Delta H_{f,298}$<br>(kJ/mol) |
|--|--------------------------------|
| CaCO <sub>3</sub>  | -1207                          |
| CaO  | -635                           |
| CO <sub>2</sub>  | -393                           |
| Al <sub>2</sub> O <sub>3</sub>   | -1669                          |
| Fe <sub>2</sub> O <sub>3</sub>   | -822                           |
| SiO <sub>2</sub>   | -908                           |
| (CaO) <sub>4</sub> .Al <sub>2</sub> O <sub>3</sub> .Fe <sub>2</sub> O <sub>3</sub> | -5080                          |
| (CaO) <sub>3</sub> .Al <sub>2</sub> O <sub>3</sub>                                 | -3561                          |
| (CaO) <sub>2</sub> .SiO <sub>2</sub>   | -2308                          |
| (CaO) <sub>3</sub> .SiO <sub>2</sub>   | -2931                          |

**$\Delta H$  reaktan**

$$\begin{aligned} \text{CaCO}_3 &= m \times c_p \times \Delta T \\ &= 376,249.4 \times 0.8609 \times (25 - 500) \\ &= -153,863,206.5 \text{ kJ/jam} \end{aligned}$$

**$\Delta H$  produk**

$$\begin{aligned} \text{CaO} &= m \times c_p \times \Delta T \\ &= 208,384.3 \times 0.7867 \times (500 - 25) \\ &= 77,872,247.2 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CO}_2 &= m \times c_p \times \Delta T \\ &= 147,357.5 \times 0.8194 \times (500 - 25) \\ &= 57,352,578.5 \text{ kJ/jam} \end{aligned}$$

**$\Delta H_f$**

$$\begin{aligned} \text{CaCO}_3 &= \text{mol} \times \Delta H_f \\ &= 3,349.0 \times -1,207 = -4,042,283,158 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CaO} &= \text{mol} \times \Delta H_f \\ &= 3,349.0 \times -635 = -2,126,636,127 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CO}_2 &= \text{mol} \times \Delta H_f \\ &= 3,349.0 \times -393 = -1,316,170,075 \text{ kJ/jam} \end{aligned}$$

Total  $\Delta H$  reaktan = -153,863,207 kJ/jam  
 Total  $\Delta H$  produk = 135,224,826 kJ/jam  
 Total  $\Delta H_f$  = 599,476,955 kJ/jam

**Total  $\Delta HR$**  = 580,838,574.60 kJ/jam

» Panas sensibel produk keluar preheater (range suhu = 860 - 875 °C)  
 temperatur produk keluar preheater = 865 °C = 1138 K  
 temperatur reference = 25 °C = 298 K

**Panas Sensibel Produk**

| Komponen                       | < 18 > ke Kiln |               | Cp (kJ/kg.K) | $\Delta T$ (K) | Hs (kJ/jam) |
|--------------------------------|----------------|---------------|--------------|----------------|-------------|
|                                | xmass          | mass (kg/jam) |              |                |             |
| CaCO <sub>3</sub>              | 0.1119         | 41,346.09     | 1.346        | 840            | 46,751,105  |
| CaO                            | 0.5639         | 208,384.29    | 1.128        | 840            | 197,484,074 |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0355         | 13,132.75     | 1.087        | 840            | 11,990,602  |
| SiO <sub>2</sub>               | 0.2067         | 76,393.63     | 1.175        | 840            | 75,411,262  |
| Al <sub>2</sub> O <sub>3</sub> | 0.0561         | 20,744.69     | 1.282        | 840            | 22,339,646  |
| MgO                            | 0.0118         | 4,362.19      | 1.242        | 840            | 4,551,166.9 |
| K <sub>2</sub> O               | 0.0039         | 1,448.88      | 1.239        | 840            | 1,507,838.2 |
| Na <sub>2</sub> O              | 0.0001         | 43.99         | 1.549        | 840            | 57,229.3    |
| SO <sub>3</sub>                | 0.0023         | 853.85        | 0.959        | 840            | 688,040.3   |
| impuritis                      | 0.0064         | 2,381.18      | 1.000        | 840            | 2,000,194.7 |
| H <sub>2</sub> O(l)            | 0.0013         | 472.07        | 4.548        | 840            | 1,803,388   |
| Total                          | 1.00           | 369,563.61    |              |                | 364,584,546 |

Qloss = (H input - (Hs Produk + Hs Gas keluar preheater +  $\Delta H_r$  kalsinasi + Hl penguapan air ))  
 = 1,500,176,250.0 - 582,261,883.3  
 = 917,914,366.76 kJ/jam

**Tabel Neraca Energi Suspension Preheater**

| H input          |                  | H output  |                  |
|------------------|------------------|-----------|------------------|
| Hs < 12 >        | 10,988,565.89    | Hs < 18 > | 364,584,546.32   |
| Hs < 17 >        | 171,776,896.03   | Hs < 16 > | 204,355,383.09   |
| Hs < 21 >        | 168,997,414.25   | Hl        | 13,321,953.85    |
| Hs < 52 >        | 1,854,383.26     | Q loss    | 917,914,366.76   |
| $\Delta HR$ Kals | 580,838,574.60   |           |                  |
| H Batubara       | 565,720,416.00   |           |                  |
| Total            | 1,500,176,250.03 | Total     | 1,500,176,250.03 |

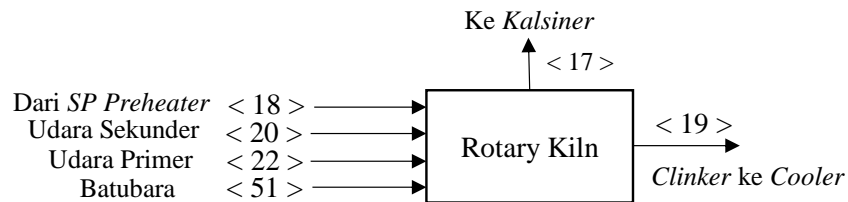
3%

## LAMPIRAN E

### APPENDIKS NERACA MASSA DAN NERACA ENERGI *ROTARY KILN* RKC 2

#### Neraca Massa

Rotary Kiln = Digunakan sebagai tempat pembakaran Kiln Feed, terjadi kalsinasi sebesar 100%, dan juga terjadi proses klinkerisasi membentuk  $C_2S$ ,  $C_3S$ ,  $C_3A$ , dan  $C_4AF$



Komponen yang masuk ke dalam Rotary Kiln :

|           |   |            |        |
|-----------|---|------------|--------|
| $CaCO_3$  | = | 41,346.09  | kg/jam |
| $CaO$     | = | 208,384.29 | kg/jam |
| $Al_2O_3$ | = | 20,744.69  | kg/jam |
| $Fe_2O_3$ | = | 13,132.75  | kg/jam |
| $SiO_2$   | = | 76,393.63  | kg/jam |

Udara sekunder = Udara panas dari *cooler*

| Komponen  | BM  |
|-----------|-----|
| $CaCO_3$  | 100 |
| $CaO$     | 56  |
| $CO_2$    | 44  |
| $C_2S$    | 172 |
| $C_3S$    | 228 |
| $C_3A$    | 270 |
| $C_4AF$   | 486 |
| $SiO_2$   | 60  |
| $Al_2O_3$ | 102 |
| $Fe_2O_3$ | 160 |

$$\text{mol} = \frac{\text{massa}}{\text{BM}}$$

Reaksi yang terjadi

Reaksi kalsinasi :



$$\text{mol } CaCO_3 \text{ mula-mula} = 413.46 \text{ kmol/jam}$$

$$\text{mol } CaO \text{ mula-mula} = 3,721.1 \text{ kmol/jam}$$

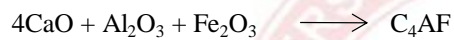
|   |   |                 |                   |   |              |   |   |               |
|---|---|-----------------|-------------------|---|--------------|---|---|---------------|
|   | 1 | $\text{CaCO}_3$ | $\longrightarrow$ | 1 | $\text{CaO}$ | + | 1 | $\text{CO}_2$ |
| m |   | 413.5           |                   |   | 3721.15      |   |   | -             |
| r |   | 413.5           |                   |   | 413.46       |   |   | 413.46        |
| s |   | -               |                   |   | 4134.61      |   |   | 413.46        |

Massa  $\text{CaCO}_3$  yang tersisa = 0 ( $\text{CaCO}_3$  habis bereaksi)

Massa  $\text{CaO}$  terbentuk = mol x BM  
 = 4,134.61 x 56  
 = 231,538.10 kg/jam

Massa  $\text{CO}_2$  terbentuk = mol x BM  
 = 413.46 x 44  
 = 18,192.28 kg/jam

Reaksi I ( $\text{Fe}_2\text{O}_3$  habis bereaksi) (Temperatur 1000 °C)



mol  $\text{CaO}$  mula-mula = 4,134.6 kmol/jam

mol  $\text{Al}_2\text{O}_3$  mula-mula = 203.38 kmol/jam

mol  $\text{Fe}_2\text{O}_3$  mula-mula = 82.08 kmol/jam

|   |   |              |   |   |                         |   |   |                         |                   |   |                       |
|---|---|--------------|---|---|-------------------------|---|---|-------------------------|-------------------|---|-----------------------|
|   | 4 | $\text{CaO}$ | + | 1 | $\text{Al}_2\text{O}_3$ | + | 1 | $\text{Fe}_2\text{O}_3$ | $\longrightarrow$ | 1 | $\text{C}_4\text{AF}$ |
| m |   | 4134.61      |   |   | 203.38                  |   |   | 82.08                   |                   |   | -                     |
| r |   | 328.32       |   |   | 82.08                   |   |   | 82.08                   |                   |   | 82.08                 |
| s |   | 3,806.29     |   |   | 121.30                  |   |   | -                       |                   |   | 82.08                 |

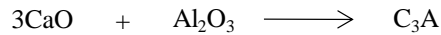
Massa  $\text{Fe}_2\text{O}_3$  tersisa = 0 ( $\text{Fe}_2\text{O}_3$  habis bereaksi)

Massa  $\text{CaO}$  yang terbentuk = mol x BM  
 = 3,806.29 x 56  
 = 213,152.26 kg/jam

Massa  $\text{Al}_2\text{O}_3$  yang terbentuk = mol x BM  
 = 121.30 x 102  
 = 12,372.56 kg/jam

Massa  $\text{C}_4\text{AF}$  yang terbentuk = mol x BM  
 = 82.08 x 486  
 = 39,890.72 kg/jam

Reaksi II ( $\text{Al}_2\text{O}_3$  habis bereaksi) (Temperatur 1100 °C)



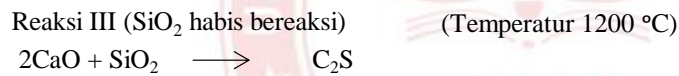
$$\begin{aligned} \text{mol CaO mula-mula} &= 3,806.29 \text{ kmol/jam} \\ \text{mol Al}_2\text{O}_3 \text{ mula-mula} &= 121.30 \text{ kmol/jam} \end{aligned}$$

|   |          |     |   |   |                                |   |   |                  |
|---|----------|-----|---|---|--------------------------------|---|---|------------------|
|   | 3        | CaO | + | 1 | Al <sub>2</sub> O <sub>3</sub> | → | 1 | C <sub>3</sub> A |
| m | 3,806.29 |     |   |   | 121.30                         |   |   | -                |
| r | 363.90   |     |   |   | 121.30                         |   |   | 121.30           |
| s | 3,442.39 |     |   |   | -                              |   |   | 121.30           |

$$\begin{aligned} \text{Massa Al}_2\text{O}_3 \text{ yang tersisa} &= 0 \text{ (Al}_2\text{O}_3 \text{ habis bereaksi)} \end{aligned}$$

$$\begin{aligned} \text{Massa CaO terbentuk} &= \text{mol} \times \text{BM} \\ &= 3,442.39 \times 56 \\ &= 192,773.92 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} \text{Massa C}_3\text{A terbentuk} &= \text{mol} \times \text{BM} \\ &= 121.30 \times 270 \\ &= 32,750.89 \text{ kg/jam} \end{aligned}$$



$$\text{mol CaO mula-mula} = 3,442.39 \text{ kmol/jam}$$

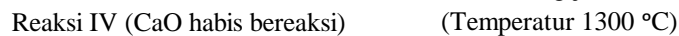
$$\text{mol SiO}_2 \text{ mula-mula} = 1,273.23 \text{ kmol/jam}$$

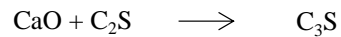
|   |          |     |   |   |                  |   |   |                  |
|---|----------|-----|---|---|------------------|---|---|------------------|
|   | 2        | CaO | + | 1 | SiO <sub>2</sub> | → | 1 | C <sub>2</sub> S |
| m | 3,442.39 |     |   |   | 1,273.23         |   |   | -                |
| r | 2,546.45 |     |   |   | 1,273.23         |   |   | 1,273.23         |
| s | 895.94   |     |   |   | -                |   |   | 1,273.23         |

$$\text{Massa SiO}_2 \text{ yang tersisa} = 0 \text{ (SiO}_2 \text{ habis bereaksi)}$$

$$\begin{aligned} \text{Massa CaO terbentuk} &= \text{mol} \times \text{BM} \\ &= 895.94 \times 56 \\ &= 50,172.48 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} \text{Massa C}_2\text{S terbentuk} &= \text{mol} \times \text{BM} \\ &= 1,273.23 \times 172 \\ &= 218,995.07 \text{ kg/jam} \end{aligned}$$





$$\begin{aligned} \text{mol CaO mula-mula} &= 895.94 \text{ kmol/jam} \\ \text{mol C}_2\text{S mula-mula} &= 1,273.23 \text{ kmol/jam} \end{aligned}$$

|   |   |        |   |   |                  |   |   |                  |
|---|---|--------|---|---|------------------|---|---|------------------|
|   | 1 | CaO    | + | 1 | C <sub>2</sub> S | → | 1 | C <sub>3</sub> S |
| m |   | 895.94 |   |   | 1,273.23         |   |   | -                |
| r |   | 895.94 |   |   | 895.94           |   |   | 895.94           |
| s |   | -      |   |   | 377.29           |   |   | 895.94           |

$$\text{Massa CaO yang tersisa} = 0 \text{ (CaO habis bereaksi)}$$

$$\begin{aligned} \text{Massa C}_2\text{S yang tersisa} &= \text{mol} \times \text{BM} \\ &= 377.29 \times 172 \\ &= 64,893.89 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} \text{Massa C}_3\text{S terbentuk} &= \text{mol} \times \text{BM} \\ &= 895.94 \times 228 \\ &= 204,273.66 \text{ kg/jam} \end{aligned}$$

$$\text{Total kebutuhan batubara} = 46,875 \text{ kg/jam}$$

$$\text{Kebutuhan batubara di Kiln} = 16,875 \text{ kg/jam}$$

#### Komposisi Batubara

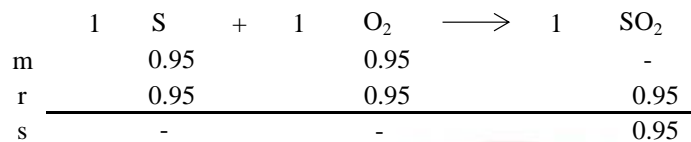
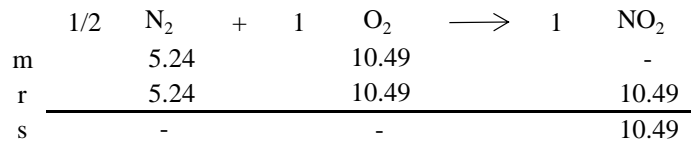
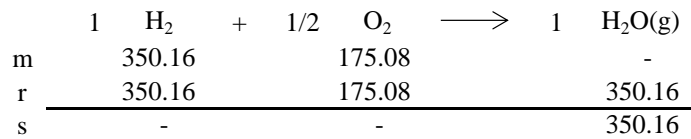
| Komponen         | % berat | Massa (kg/jam) |
|------------------|---------|----------------|
| C                | 53.43   | 9,016.31       |
| H                | 4.15    | 700.31         |
| N                | 0.87    | 146.81         |
| O                | 23.24   | 3,921.75       |
| S                | 0.18    | 30.38          |
| H <sub>2</sub> O | 14.88   | 2,511.00       |
| Ash              | 3.25    | 548.44         |
| Total            | 100.00  | 16,875         |

#### BM masing-masing komponen :

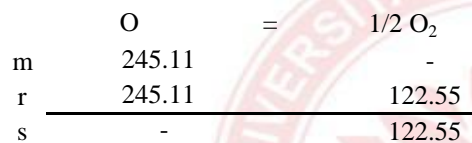
| Komponen         | BM |
|------------------|----|
| C                | 12 |
| H                | 1  |
| N                | 14 |
| O                | 16 |
| S                | 32 |
| CO <sub>2</sub>  | 44 |
| H <sub>2</sub> O | 18 |
| NO <sub>2</sub>  | 46 |
| SO <sub>2</sub>  | 64 |

Reaksi pembakaran komponen batu bara :

|   |   |        |   |   |                |   |   |                 |
|---|---|--------|---|---|----------------|---|---|-----------------|
|   | 1 | C      | + | 1 | O <sub>2</sub> | → | 1 | CO <sub>2</sub> |
| m |   | 751.36 |   |   | 751.4          |   |   | -               |
| r |   | 751.4  |   |   | 751.4          |   |   | 751.4           |
| s |   | -      |   |   | -              |   |   | 751.4           |



O<sub>2</sub> yang terkandung dalam batu bara :



$$\begin{aligned}
 \text{Kebutuhan O}_2 \text{ dari} &= 751.36 + 175.08 + 10.49 + 0.949 \\
 \text{reaksi pembakaran} &= 937.87 \text{ kmol/jam} \\
 &= 30,011.95 \text{ kg/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{O}_2 \text{ yang terkandung dalam batu bara} &= 3,921.75 \text{ kg/jam} \\
 \text{Kebutuhan O}_2 \text{ stoikiometris} &= 30,011.95 - 3,921.75 \\
 &= 26,090.20 \text{ kg/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{Kebutuhan O}_2 + \text{O}_2 \text{ ekkses} &= 26,742.45 \text{ kg/jam} \\
 (\text{asumsi udara ekkses} = 2.5\%) & \quad \quad \quad (\text{FLSmidth Institute})
 \end{aligned}$$

| Perhitungan Fraksi Massa Udara |            |    |              |
|--------------------------------|------------|----|--------------|
| Komponen                       | Fraksi mol | BM | Fraksi massa |
| O <sub>2</sub>                 | 0.21       | 32 | 0.23         |
| N <sub>2</sub>                 | 0.79       | 28 | 0.77         |
| Total                          | 1.00       |    | 1.00         |

$$\begin{aligned}
 \text{Total udara stoikiometris} &= 100 \\
 + \text{ udara ekkses} &= \frac{23}{23} \times 26,742 = 114,769.69 \text{ kg/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{Udara dari} &= 0.25 \frac{\text{kg udara}}{\text{kg batubara}} \times 16,875 = 4,219 \text{ kg/jam} \\
 \text{conveyor batu bara} &
 \end{aligned}$$



Udara = 114,769.69 - 4,218.75 - 100,785.0  
 primer = 9,765.93 kg/jam

**Neraca Massa Rotary Kiln**

| Input                          |                       |               | Output            |                  |               |
|--------------------------------|-----------------------|---------------|-------------------|------------------|---------------|
| Komponen                       | < 18 > output dari SP |               | Komponen          | < 19 > ke Cooler |               |
|                                | xmass                 | mass (kg/jam) |                   | xmass            | mass (kg/jam) |
| CaCO <sub>3</sub>              | 0.1119                | 41,346.09     | C <sub>3</sub> A  | 0.0931           | 32,750.89     |
| CaO                            | 0.5639                | 208,384.29    | C <sub>4</sub> AF | 0.1134           | 39,890.72     |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0355                | 13,132.75     | C <sub>2</sub> S  | 0.1844           | 64,893.89     |
| SiO <sub>2</sub>               | 0.2067                | 76,393.63     | C <sub>3</sub> S  | 0.5805           | 204,273.66    |
| Al <sub>2</sub> O <sub>3</sub> | 0.0561                | 20,744.69     | Na <sub>2</sub> O | 0.0001           | 43.99         |
| MgO                            | 0.0118                | 4,362.19      | K <sub>2</sub> O  | 0.0041           | 1,448.88      |
| K <sub>2</sub> O               | 0.0039                | 1,448.88      | SO <sub>3</sub>   | 0.0024           | 853.85        |
| Na <sub>2</sub> O              | 0.0001                | 43.99         | MgO               | 0.0124           | 4,362.19      |
| SO <sub>3</sub>                | 0.0023                | 853.85        | impuritis         | 0.0097           | 3,401.69      |
| impuritis                      | 0.0064                | 2,381.18      |                   |                  |               |
| H <sub>2</sub> O               | 0.0013                | 472.07        |                   |                  |               |
| Total                          | 1.00                  | 369,563.61    | Total             | 1.00             | 351,919.77    |

| Input               |                 |               | Output              |                    |               |
|---------------------|-----------------|---------------|---------------------|--------------------|---------------|
| Komponen            | < 51 > Batubara |               | Komponen            | < 17 > ke Kalsiner |               |
|                     | xmass           | mass (kg/jam) |                     | xmass              | mass (kg/jam) |
| C                   | 0.5343          | 9,016.31      | O <sub>2</sub>      | 0.0044             | 652.25        |
| H                   | 0.0415          | 700.31        | N <sub>2</sub>      | 0.5896             | 88,027.24     |
| N                   | 0.0087          | 146.81        | CO <sub>2</sub>     | 0.3433             | 51,252.09     |
| O                   | 0.2324          | 3,921.75      | H <sub>2</sub> O(g) | 0.0590             | 8,813.81      |
| S                   | 0.0018          | 30.38         | NO <sub>2</sub>     | 0.0032             | 482.38        |
| H <sub>2</sub> O(l) | 0.1488          | 2,511         | SO <sub>2</sub>     | 0.0004             | 60.75         |
| Ash                 | 0.0325          | 548.44        |                     |                    |               |
| Total               | 1.00            | 16,875        | Total               | 1.00               | 149,288.53    |

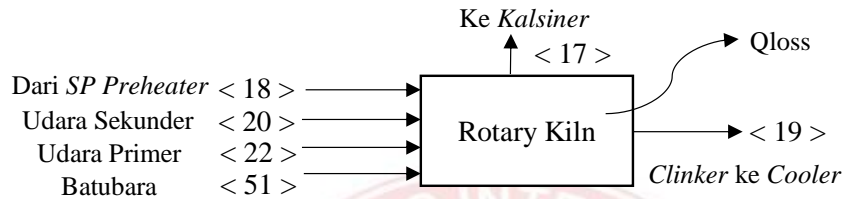
| Input          |                 |               |
|----------------|-----------------|---------------|
| Komponen       | < 51 > Batubara |               |
|                | xmass           | mass (kg/jam) |
| O <sub>2</sub> | 0.2330          | 983.01        |
| N <sub>2</sub> | 0.7670          | 3,235.74      |
| Total          | 1.00            | 4,218.75      |

| Input          |                       |               |
|----------------|-----------------------|---------------|
| Komponen       | < 20 > Udara Sekunder |               |
|                | xmass                 | mass (kg/jam) |
| O <sub>2</sub> | 0.2330                | 23,483.88     |
| N <sub>2</sub> | 0.7670                | 77,301.12     |
| Total          | 1.00                  | 100,785.01    |

| Input |  |  |
|-------|--|--|
|-------|--|--|

| Komponen       | < 22 > Udara Primer |               |
|----------------|---------------------|---------------|
|                | xmass               | mass (kg/jam) |
| O <sub>2</sub> | 0.2330              | 2,275.56      |
| N <sub>2</sub> | 0.7670              | 7,490.37      |
| Total          | 1.00                | 9,765.93      |
|                |                     | 501,208.298   |
|                |                     | 501,208.298   |

### Neraca Energi



|  |   |      |    |   |        |
|--|---|------|----|---|--------|
| » Neraca energi masuk dari Preheater : |   |      |    |   |        |
| temperatur bahan masuk                 | = | 865  | °C | = | 1138 K |
| temperatur bahan keluar                | = | 1350 | °C | = | 1623 K |
| temperatur reference                   | = | 25   | °C | = | 298 K  |

| Komponen                       | < 18 > dari output SP |               | Cp (kJ/kg.K) | ΔT (K) | Hs (kJ/jam)   |
|--------------------------------|-----------------------|---------------|--------------|--------|---------------|
|                                | xmass                 | mass (kg/jam) |              |        |               |
| CaCO <sub>3</sub>              | 0.1119                | 41,346.09     | 1.346        | 840    | 46,751,104.66 |
| CaO                            | 0.5639                | 208,384.29    | 1.128        | 840    | 197,484,074.2 |
| Fe <sub>2</sub> O <sub>3</sub> | 0.0355                | 13,132.75     | 1.087        | 840    | 11,990,602.21 |
| SiO <sub>2</sub>               | 0.2067                | 76,393.63     | 1.175        | 840    | 75,411,261.66 |
| Al <sub>2</sub> O <sub>3</sub> | 0.0561                | 20,744.69     | 1.282        | 840    | 22,339,646.09 |
| MgO                            | 0.0118                | 4,362.19      | 1.242        | 840    | 4,551,166.93  |
| K <sub>2</sub> O               | 0.0039                | 1,448.88      | 1.239        | 840    | 1,507,838.22  |
| Na <sub>2</sub> O              | 0.0001                | 43.99         | 1.549        | 840    | 57,229.27     |
| SO <sub>3</sub>                | 0.0023                | 853.85        | 0.959        | 840    | 688,040.26    |
| impuritis                      | 0.0064                | 2,381.18      | 1.000        | 840    | 2,000,194.69  |
| H <sub>2</sub> O               | 0.0013                | 472.07        | 4.548        | 840    | 1,803,388.17  |
| Total                          | 1.00                  | 369,563.61    |              |        | 364,584,546.3 |

### Neraca Energi Reaksi di Kiln :

Panas Kalsinasi Lanjut (Setelah kalsinasi di Preheater)

|   |   |                   |   |   |          |   |   |                 |
|---|---|-------------------|---|---|----------|---|---|-----------------|
|   | 1 | CaCO <sub>3</sub> | → | 1 | CaO      | + | 1 | CO <sub>2</sub> |
| m |   | 413.46            |   |   | 3,721.15 |   |   | -               |
| r |   | 413.46            |   |   | 413.46   |   |   | 413.46          |
| s |   | -                 |   |   | 4,134.61 |   |   | 413.46          |

ΔH reaktan

$$\begin{aligned} \text{CaCO}_3 &= m \times \text{cp} \times \Delta T \\ &= 41,346.09 \times 1.3461 \times (25 - 900) \\ &= -48,699,067.4 \text{ kJ/jam} \end{aligned}$$

**$\Delta H$  produk**

$$\begin{aligned} \text{CaO} &= m \times \text{cp} \times \Delta T \\ &= 231,538.10 \times 1.1282 \times (900 - 25) \\ &= 228,569,530.3 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CO}_2 &= m \times \text{cp} \times \Delta T \\ &= 18,192.28 \times 1.0869 \times (900 - 25) \\ &= 17,302,197.9 \text{ kJ/jam} \end{aligned}$$

**$\Delta H_f$**

$$\begin{aligned} \text{CaCO}_3 &= \text{mol} \times \Delta H_f \\ &= 413.5 \times -1,207 = -499,047,303 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CaO} &= \text{mol} \times \Delta H_f \\ &= 413.5 \times -635 = -262,547,670 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{CO}_2 &= \text{mol} \times \Delta H_f \\ &= 413.5 \times -393 = -162,490,133 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{Total } \Delta H \text{ reaktan} &= -48,699,067 \text{ kJ/jam} \\ \text{Total } \Delta H \text{ produk} &= 245,871,728 \text{ kJ/jam} \\ \text{Total } \Delta H_f &= 74,009,501 \text{ kJ/jam} \end{aligned}$$

$$\text{Total } \Delta H_R = 271,182,161.49 \text{ kJ/jam}$$

Panas enthalpy reaksi pembentukan klinker :

**Reaksi I:**

|   |          |   |   |                                |   |   |                                |   |   |                   |
|---|----------|---|---|--------------------------------|---|---|--------------------------------|---|---|-------------------|
| 4 | CaO      | + | 1 | Al <sub>2</sub> O <sub>3</sub> | + | 1 | Fe <sub>2</sub> O <sub>3</sub> | → | 1 | C <sub>4</sub> AF |
| m | 4,134.61 |   |   | 203.38                         |   |   | 82.08                          |   |   | -                 |
| r | 328.32   |   |   | 82.08                          |   |   | 82.08                          |   |   | 82.08             |
| s | 3,806.29 |   |   | 121.30                         |   |   | -                              |   |   | 82.08             |

**$\Delta H$  reaktan**

$$\begin{aligned} \text{CaO} &= m \times \text{cp} \times \Delta T \\ &= 231,538.10 \times 1.1282 \times (25 - 1000) \\ &= -254,691,762.32 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{Al}_2\text{O}_3 &= m \times \text{cp} \times \Delta T \\ &= 20,744.69 \times 1.2820 \times (25 - 1000) \\ &= -25,929,946.35 \text{ kJ/jam} \end{aligned}$$

$$\text{Fe}_2\text{O}_3 = m \times \text{cp} \times \Delta T$$

$$= 13,132.75 \times 1.0869 \times (25 - 1000)$$

$$= -13,917,663.28 \text{ kJ/jam}$$

**$\Delta H$  produk**

$$\text{C}_4\text{AF} = m \times c_p \times \Delta T$$

$$= 39,890.72 \times 3.4938 \times (1000 - 25)$$

$$= 135,887,361.39 \text{ kJ/jam}$$

**$\Delta H_f$**

$$\text{CaO} = \text{mol} \times \Delta H_f$$

$$= 328.3 \times -635 = -208,482,373 \text{ kJ/jam}$$

$$\text{Al}_2\text{O}_3 = \text{mol} \times \Delta H_f$$

$$= 82.1 \times -1,669 = -136,990,976 \text{ kJ/jam}$$

$$\text{Fe}_2\text{O}_3 = \text{mol} \times \Delta H_f$$

$$= 82.1 \times -822 = -67,469,492 \text{ kJ/jam}$$

$$\text{C}_4\text{AF} = \text{mol} \times \Delta H_f$$

$$= 82.1 \times -5,080 = -416,964,745 \text{ kJ/jam}$$

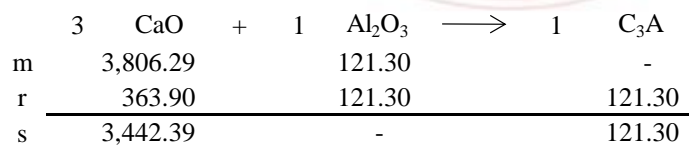
$$\text{Total } \Delta H \text{ reaktan} = -294,539,372 \text{ kJ/jam}$$

$$\text{Total } \Delta H \text{ produk} = 135,887,361 \text{ kJ/jam}$$

$$\text{Total } \Delta H_f = -4,021,904 \text{ kJ/jam}$$

$$\text{Total } \Delta H R 1 = -162,673,914.60 \text{ kJ/jam}$$

**Reaksi II :**



**$\Delta H$  reaktan**

$$\text{CaO} = m \times c_p \times \Delta T$$

$$= 213,152.26 \times 1.1282 \times (25 - 1100)$$

$$= -258,515,275.10 \text{ kJ/jam}$$

$$\text{Al}_2\text{O}_3 = m \times c_p \times \Delta T$$

$$= 12,372.56 \times 1.2820 \times (25 - 1100)$$

$$= -17,051,325.56 \text{ kJ/jam}$$

**$\Delta H$  produk**

$$\begin{aligned}
 C_3A &= m \times cp \times \Delta T \\
 &= 32,750.89 \times 1.6929 \times (1100 - 25) \\
 &= 59,603,934.51 \text{ kJ/jam}
 \end{aligned}$$

**$\Delta H_f$**

$$\begin{aligned}
 CaO &= mol \times \Delta H_f \\
 &= 363.9 \times -635 = -231,075,744 \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 Al_2O_3 &= mol \times \Delta H_f \\
 &= 121.3 \times -1,669 = -202,449,037 \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 C_3A &= mol \times \Delta H_f \\
 &= 121.3 \times -3,561 = -431,947,886 \text{ kJ/jam}
 \end{aligned}$$

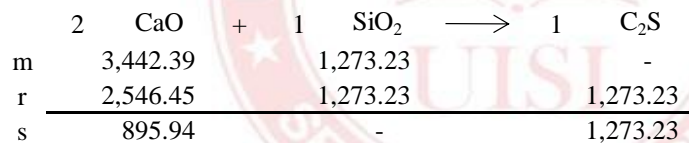
$$\text{Total } \Delta H \text{ reaktan} = -275,566,601 \text{ kJ/jam}$$

$$\text{Total } \Delta H \text{ produk} = 59,603,935 \text{ kJ/jam}$$

$$\text{Total } \Delta H_f = 1,576,895 \text{ kJ/jam}$$

$$\text{Total } \Delta H R 2 = -214,385,771.31 \text{ kJ/jam}$$

**Reaksi III :**



**$\Delta H$  reaktan**

$$\begin{aligned}
 CaO &= m \times cp \times \Delta T \\
 &= 192,773.92 \times 1.1282 \times (25 - 1200) \\
 &= -255,548,869.01 \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned}
 SiO_2 &= m \times cp \times \Delta T \\
 &= 76,393.63 \times 1.1752 \times (25 - 1200) \\
 &= -105,485,991.02 \text{ kJ/jam}
 \end{aligned}$$

**$\Delta H$  produk**

$$\begin{aligned}
 C_2S &= m \times cp \times \Delta T \\
 &= 218,995.07 \times 1.2190 \times (1200 - 25) \\
 &= 313,673,199.51 \text{ kJ/jam}
 \end{aligned}$$

**$\Delta H_f$**

$$\begin{aligned}
 CaO &= mol \times \Delta H_f \\
 &= 2,546.5 \times -635 = -1,616,998,508 \text{ kJ/jam}
 \end{aligned}$$

$$\begin{aligned} \text{SiO}_2 &= \text{mol} \times \Delta H_f \\ &= 1,273.2 \times -908 = -1,156,090,272 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{C}_2\text{S} &= \text{mol} \times \Delta H_f \\ &= 1,273.2 \times -2,308 = -2,938,608,313 \text{ kJ/jam} \end{aligned}$$

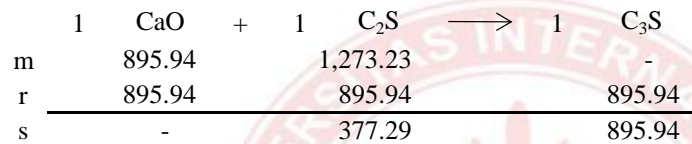
$$\text{Total } \Delta H \text{ reaktan} = -361,034,860 \text{ kJ/jam}$$

$$\text{Total } \Delta H \text{ produk} = 313,673,200 \text{ kJ/jam}$$

$$\text{Total } \Delta H_f = -165,519,532 \text{ kJ/jam}$$

$$\text{Total } \Delta H R 3 = -212,881,192.87 \text{ kJ/jam}$$

#### Reaksi IV :



#### **ΔH reaktan**

$$\begin{aligned} \text{CaO} &= m \times c_p \times \Delta T \\ &= 50,172.48 \times 1.1282 \times (25 - 1300) \\ &= -72,171,138.76 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{C}_2\text{S} &= m \times c_p \times \Delta T \\ &= 218,995.07 \times 1.2190 \times (25 - 1300) \\ &= -340,368,790.95 \text{ kJ/jam} \end{aligned}$$

#### **ΔH produk**

$$\begin{aligned} \text{C}_3\text{S} &= m \times c_p \times \Delta T \\ &= 204,273.66 \times 1.1654 \times (1300 - 25) \\ &= 303,516,728.14 \text{ kJ/jam} \end{aligned}$$

#### **ΔHf**

$$\begin{aligned} \text{CaO} &= \text{mol} \times \Delta H_f \\ &= 895.9 \times -635 = -568,920,075 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{C}_2\text{S} &= \text{mol} \times \Delta H_f \\ &= 895.9 \times -2,308 = -2,067,822,888 \text{ kJ/jam} \end{aligned}$$

$$\begin{aligned} \text{C}_3\text{S} &= \text{mol} \times \Delta H_f \\ &= 895.9 \times -2,931 = -2,625,991,717 \text{ kJ/jam} \end{aligned}$$

$$\text{Total } \Delta H \text{ reaktan} = -412,539,930 \text{ kJ/jam}$$

Total  $\Delta H$  produk = 303,516,728 kJ/jam

Total  $\Delta H_f$  = 10,751,246 kJ/jam

**Total  $\Delta H R_4$  = -98,271,956.06 kJ/jam**

Total  $\Delta H R$  (reaksi kalsinasi + klinkerisasi) = -417,030,673.35 kJ/jam

» Neraca energi pembakaran batubara

Massa batubara = 16,875 kg/jam

Heating value = 4,504 kkal/kg

H batubara = 16,875 x 4,504

= 76,005,000 kkal/jam

= 318,217,734 kJ/jam

|                      |   |       |   |       |
|----------------------|---|-------|---|-------|
| temperatur batubara  | = | 55 °C | = | 328 K |
| temperatur reference | = | 25 °C | = | 298 K |

(range suhu : 50 - 66 °C)

**Panas Sensibel Batubara  
Stream 51**

| Komponen            | < 51 > Batubara |               | Cp<br>(kJ/kg.K) | $\Delta T$ (K)  | Hs (kJ/jam)  |
|---------------------|-----------------|---------------|-----------------|-----------------|--------------|
|                     | xmass           | mass (kg/jam) |                 |                 |              |
| C                   | 0.5343          | 9,016.31      | 0.8365          | 30              | 226,272.61   |
| H                   | 0.0415          | 700.31        | 14.397          | 30              | 302,463.74   |
| N                   | 0.0087          | 146.81        | 1.0255          | 30              | 4,516.67     |
| O                   | 0.2324          | 3,921.75      | 0.9184          | 30              | 108,050.52   |
| S                   | 0.0018          | 30.38         | 0.7450          | 30              | 678.91       |
| H <sub>2</sub> O(l) | 0.1488          | 2,511.00      | 4.2019          | 30              | 316,526.74   |
| Ash                 | 0.0325          | 548.44        | 1.000           | 30              | 16,453.13    |
| Total               | 1.00            | 16,875.00     |                 |                 | 974,962.33   |
| Komponen            | < 51 > Batubara |               | Cp<br>(kJ/kg.K) | $\Delta T$ (°C) | Hs (kJ/jam)  |
|                     | xmass           | mass (kg/jam) |                 |                 |              |
| O <sub>2</sub>      | 0.2330          | 983.01        | 0.918           | 30              | 27,083.50    |
| N <sub>2</sub>      | 0.7670          | 3,235.74      | 1.025           | 30              | 99,547.28    |
| Total               | 1.00            | 4,218.75      |                 |                 | 126,630.78   |
| Total               |                 |               |                 |                 | 1,101,593.11 |

|                           |   |          |   |         |
|---------------------------|---|----------|---|---------|
| temperatur udara sekunder | = | 1,100 °C | = | 1,373 K |
| temperatur reference      | = | 25 °C    | = | 298 K   |

**Stream 20**

| Komponen       | < 20 > Udara Sekunder |               | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | Hs (kJ/jam)   |
|----------------|-----------------------|---------------|-----------------|----------------|---------------|
|                | xmass                 | mass (kg/jam) |                 |                |               |
| O <sub>2</sub> | 0.2330                | 23,483.88     | 1.05018         | 1,075          | 26,512,050.9  |
| N <sub>2</sub> | 0.7670                | 77,301.12     | 1.12215         | 1,075          | 93,249,009.4  |
| Total          | 1.00                  | 100,785.01    |                 |                | 119,761,060.3 |

|                         |   |       |   |       |
|-------------------------|---|-------|---|-------|
| temperatur udara primer | = | 30 °C | = | 303 K |
| temperatur reference    | = | 25 °C | = | 298 K |

#### Stream 22

| Komponen       | < 22 > Udara Primer |               | Cp<br>(kJ/kg.K) | ΔT (°C) | Hs (kJ/jam) |
|----------------|---------------------|---------------|-----------------|---------|-------------|
|                | xmass               | mass (kg/jam) |                 |         |             |
| O <sub>2</sub> | 0.2330              | 2,275.56      | 0.916           | 5       | 10,420.65   |
| N <sub>2</sub> | 0.7670              | 7,490.37      | 1.024           | 5       | 38,337.84   |
| Total          | 1.00                | 9,765.93      |                 |         | 48,758.49   |

|                          |   |         |   |        |
|--------------------------|---|---------|---|--------|
| temperatur gas dari kiln | = | 1000 °C | = | 1273 K |
| temperatur reference     | = | 25 °C   | = | 298 K  |

#### Panas Sensibel Gas dari Kiln

##### Stream 17

| Komponen            | < 17 > ke Kalsiner |               | Cp<br>(kJ/kg.K) | ΔT (K) | Hs (kJ/jam)   |
|---------------------|--------------------|---------------|-----------------|--------|---------------|
|                     | xmass              | mass (kg/jam) |                 |        |               |
| CO <sub>2</sub>     | 0.3433             | 51,252.09     | 1.134           | 975    | 56,660,016.93 |
| H <sub>2</sub> O(g) | 0.0590             | 8,813.81      | 2.134           | 975    | 18,337,063.8  |
| NO <sub>2</sub>     | 0.0032             | 482.38        | 1.167           | 975    | 548,675.79    |
| SO <sub>2</sub>     | 0.0004             | 60.75         | 1.038           | 975    | 61,460.17     |
| O <sub>2</sub>      | 0.0044             | 652.25        | 1.113           | 975    | 707,774.33    |
| N <sub>2</sub>      | 0.5896             | 88,027.24     | 0.865           | 975    | 74,212,385.98 |
| Total               | 1.00               | 149,288.53    |                 |        | 150,527,377.0 |

|                      |   |         |   |        |
|----------------------|---|---------|---|--------|
| temperatur klinker   | = | 1350 °C | = | 1623 K |
| temperatur reference | = | 25 °C   | = | 298 K  |

#### Panas Sensibel Klinker Keluar

##### Stream 19

| Komponen          | < 19 > menuju ke Cooler |               | Cp<br>(kJ/kg.K) | ΔT (K) | Hs (kJ/jam)   |
|-------------------|-------------------------|---------------|-----------------|--------|---------------|
|                   | xmass                   | mass (kg/jam) |                 |        |               |
| C <sub>3</sub> A  | 0.0931                  | 32,750.89     | 1.693           | 1,325  | 73,465,314.6  |
| C <sub>4</sub> AF | 0.1134                  | 39,890.72     | 3.494           | 1,325  | 184,667,439.8 |
| C <sub>2</sub> S  | 0.1844                  | 64,893.89     | 1.219           | 1,325  | 104,815,346   |
| C <sub>3</sub> S  | 0.5805                  | 204,273.66    | 1.165           | 1,325  | 315,419,345   |
| Na <sub>2</sub> O | 0.0001                  | 43.99         | 1.622           | 1,325  | 94,557.1      |
| K <sub>2</sub> O  | 0.0041                  | 1,448.88      | 1.476           | 1,325  | 2,834,216.6   |
| SO <sub>3</sub>   | 0.0024                  | 853.85        | 1.002           | 1,325  | 1,133,727.7   |
| MgO               | 0.0124                  | 4,362.19      | 1.321           | 1,325  | 7,635,194.5   |
| impuritis         | 0.0097                  | 3,401.69      | 1.000           | 1,325  | 4,507,241.4   |
| Total             | 1.00                    | 351,919.77    |                 |        | 694,572,383.2 |



$$\begin{aligned}
 Q_{\text{loss}} &= (\text{H input} - (\Delta\text{H Produk} + \Delta\text{H Gas buang Kiln})) \\
 &= 1,220,744,365.6 - 845,099,760.22 \\
 &= 375,644,605.39 \text{ kJ/jam}
 \end{aligned}$$

**Tabel Neraca Energi Rotary Kiln**

| IN                |                 | OUT       |                 |
|-------------------|-----------------|-----------|-----------------|
| H input           |                 | H output  |                 |
| Hs < 18 >         | 364,584,546.3   | Hs < 17 > | 150,527,377.0   |
| Hs < 20 >         | 119,761,060.3   | Hs < 19 > | 694,572,383.2   |
| Hs < 22 >         | 48,758.5        | Q loss    | 375,644,605.4   |
| Hs < 51 >         | 1,101,593.1     |           |                 |
| $\Delta\text{HR}$ | 417,030,673.3   |           |                 |
| H Batubara        | 318,217,734.0   |           |                 |
| Total             | 1,220,744,365.6 | Total     | 1,220,744,365.6 |

$$\text{Efisiensi Energi di Kiln} = 69.2\%$$

$$\text{Heat Loss di Kiln} = 30.8\%$$

$$T = 325 \text{ } ^\circ\text{C} = 598 \text{ K} \quad (\text{temperatur dinding kiln})$$

$$T_o = 30 \text{ } ^\circ\text{C} = 303 \text{ K} \quad (\text{temperatur lingkungan})$$

$$\text{Radiation Loss} = 4 \times 10^{-8} \times (T^4 - T_o^4)$$

$$= 446.2332 \text{ kkal/jam.m}^2$$

$$= 1,867.0398 \text{ kJ/jam.m}^2$$

$$\text{Convection Loss} = 80,33 \times \left(\frac{T + T_o}{2}\right)^{-0,724} \times (T - T_o)^{1,333}$$

$$= 3,704.5111 \text{ kkal/jam.m}^2$$

$$= 15,499.6746 \text{ kJ/jam.m}^2$$

$$\text{Perbandingan heat loss secara konduksi, radiasi, konveksi} = 1 : 33 : 4$$

$$\% \text{ radiation loss} = 0.81\%$$

$$\text{nilai radiation loss} = 9,894,424.44 \text{ kJ/jam}$$

$$= 2,748.45 \text{ kJ/s}$$

$$= 2,748.45 \text{ kW}$$

$$= 65,962.83 \text{ kWh/hari}$$

$$\% \text{ convection loss} = 26.74\%$$

$$\text{nilai convection loss} = 326,429,550.96 \text{ kJ/jam}$$

$$= 90,674.88 \text{ kJ/s}$$

$$= 90,674.88 \text{ kW}$$

$$= 2,176,197.01 \text{ kWh/hari}$$

Nilai K → Refraktori (bata tahan api) = 2.9 W/m.K  
 Baja = 80.2 W/m.K

Diameter kiln = 5.6 m

Panjang kiln = 84 m

Ketebalan dinding permukaan kiln = 0.05 m

Nilai A = keliling permukaan kiln x panjang kiln  
 = 17.584 x 84  
 = 1,477.06 m<sup>2</sup>

Conduction Loss =  $k \times A \times \left(\frac{\Delta T}{X}\right)$

proporsi kehilangan = 25,272,428.16 Watt

panas secara konduksi = 61,596.00 kJ/jam.m<sup>2</sup>

% conduction loss = 3.22%

nilai conduction loss = 39,320,629.98 kJ/jam

= 10,922.40 kJ/s

= 10,922.40 kW

= 262,137.53 kWh/hari

Konversi kehilangan panas terhadap jumlah batubara yang dapat dimanfaatkan :

Jumlah Batubara = Total panas yang hilang / nilai bakar batubara

=  $\frac{89,779,060.7}{4,504}$

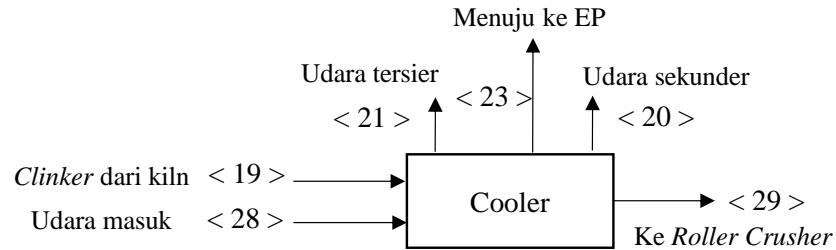
= 19,933.2

= 19.9 kg/jam

= 19.9 ton/jam

= 478.4 ton/hari

**LAMPIRAN F**  
**APPENDIKS NERACA MASSA DAN NERACA ENERGI COOLER RKC 2**  
**Neraca Massa**



Keterangan :

Fungsi Cooler = Berfungsi untuk mendinginkan *clinker*

- Asumsi 1. Debu *clinker* tidak ada yang terbawa ke udara tersier dan sekunder karena tertahan *dust trap*  
 2. 1% debu *clinker* yang terbawa udara ke EP

Massa *clinker* yang masuk ke Cooler = 351,919.77 kg/jam

Massa debu *clinker* yang terikut ke EP :

$$\begin{aligned} C_3A &= 1\% \times \text{clinker} & \text{impuritis} &= 1\% \times \text{clinker} \\ &= 327.5 \text{ kg/jam} & &= 34.0 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} C_4AF &= 1\% \times \text{clinker} \\ &= 398.9 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} C_2S &= 1\% \times \text{clinker} \\ &= 648.9 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} C_3S &= 1\% \times \text{clinker} \\ &= 2,042.7 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} Na_2O &= 1\% \times \text{clinker} \\ &= 0.440 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} K_2O &= 1\% \times \text{clinker} \\ &= 14.489 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} SO_3 &= 1\% \times \text{clinker} \\ &= 8.5 \text{ kg/jam} \end{aligned}$$

$$MgO = 1\% \times \text{clinker}$$

$$= 43.6 \text{ kg/jam}$$

*clinker* ke crusher = *clinker* masuk Cooler - *clinker* yang terbawa ke EP

|                   |   |            |   |          |   |            |        |
|-------------------|---|------------|---|----------|---|------------|--------|
| C <sub>3</sub> A  | = | 32,750.89  | - | 327.51   | = | 32,423.38  | kg/jam |
| C <sub>4</sub> AF | = | 39,890.72  | - | 398.91   | = | 39,491.81  | kg/jam |
| C <sub>2</sub> S  | = | 64,893.89  | - | 648.94   | = | 64,244.95  | kg/jam |
| C <sub>3</sub> S  | = | 204,273.66 | - | 2,042.74 | = | 202,230.93 | kg/jam |
| Na <sub>2</sub> O | = | 43.99      | - | 0.44     | = | 43.55      | kg/jam |
| K <sub>2</sub> O  | = | 1,448.88   | - | 14.49    | = | 1,434.39   | kg/jam |
| SO <sub>3</sub>   | = | 853.85     | - | 8.54     | = | 845.31     | kg/jam |
| MgO               | = | 4,362.19   | - | 43.62    | = | 4,318.57   | kg/jam |
| imprtis           | = | 3,401.69   | - | 34.02    | = | 3,367.67   | kg/jam |

$$\begin{aligned} \text{Massa udara masuk ke Cooler} &= 1.81 \text{ kg udara/kg terak} \\ &= 636,974.78 \text{ kg/jam} \end{aligned}$$

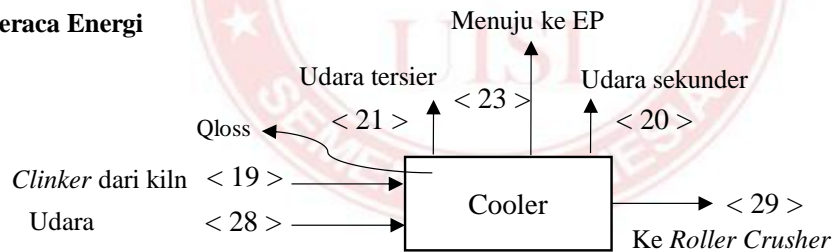
$$\begin{aligned} \text{Total massa udara sekunder} &= 16\% \text{ dari udara masuk Cooler} \\ &= 100,785.01 \text{ kg/jam} \end{aligned}$$

$$\text{Massa udara ke EP} = 339,654.78 \text{ kg/jam}$$

| Input             |                         |               | Output            |                          |               |
|-------------------|-------------------------|---------------|-------------------|--------------------------|---------------|
| Komponen          | < 19 > dari output kiln |               | Komponen          | < 29 > ke roller crusher |               |
|                   | xmass                   | mass (kg/jam) |                   | xmass                    | mass (kg/jam) |
| C <sub>3</sub> A  | 0.09306                 | 32,750.89     | C <sub>3</sub> A  | 0.09306                  | 32,423.38     |
| C <sub>4</sub> AF | 0.11335                 | 39,890.72     | C <sub>4</sub> AF | 0.11335                  | 39,491.81     |
| C <sub>2</sub> S  | 0.18440                 | 64,893.89     | C <sub>2</sub> S  | 0.18440                  | 64,244.95     |
| C <sub>3</sub> S  | 0.58046                 | 204,273.66    | C <sub>3</sub> S  | 0.58046                  | 202,230.93    |
| Na <sub>2</sub> O | 0.00013                 | 43.99         | Na <sub>2</sub> O | 0.00013                  | 43.55         |
| K <sub>2</sub> O  | 0.00412                 | 1,448.88      | K <sub>2</sub> O  | 0.00412                  | 1,434.39      |
| SO <sub>3</sub>   | 0.00243                 | 853.85        | SO <sub>3</sub>   | 0.00243                  | 845.31        |
| MgO               | 0.01240                 | 4,362.19      | MgO               | 0.01240                  | 4,318.57      |
| impuritis         | 0.00967                 | 3,401.69      | impuritis         | 0.00967                  | 3,367.67      |
| Total             | 1.00                    | 351,919.77    | Total             | 1.00                     | 348,400.57    |
| Input             |                         |               | Output            |                          |               |
| Komponen          | < 28 > udara masuk      |               | Komponen          | < 21 > udara tersier     |               |
|                   | xmass                   | mass (kg/jam) |                   | xmass                    | mass (kg/jam) |
| O <sub>2</sub>    | 0.23301                 | 148,421.31    | O <sub>2</sub>    | 0.23301                  | 45,794.56     |
| N <sub>2</sub>    | 0.76699                 | 488,553.47    | N <sub>2</sub>    | 0.76699                  | 150,740.44    |
| Total             | 1.00                    | 636,974.78    | Total             | 1.00                     | 196,535.00    |
|                   |                         |               | Output            |                          |               |
| Komponen          | < 20 > udara sekunder   |               | Komponen          | < 20 > udara sekunder    |               |
|                   | xmass                   | mass (kg/jam) |                   | xmass                    | mass (kg/jam) |
| O <sub>2</sub>    | 0.23301                 | 148,421.31    | O <sub>2</sub>    | 0.23301                  | 23,483.88     |

|                |                   |                     |                     |  |
|----------------|-------------------|---------------------|---------------------|--|
|                | N <sub>2</sub>    | 0.76699             | 77,301.12           |  |
|                | Total             | 1.00                | 100,785.01          |  |
|                | <b>Output</b>     |                     |                     |  |
|                | Komponen          | < 23 > menuju ke EP |                     |  |
|                |                   | xmass               | mass (kg/jam)       |  |
|                | C <sub>3</sub> A  | 0.09306             | 327.51              |  |
|                | C <sub>4</sub> AF | 0.11335             | 398.91              |  |
|                | C <sub>2</sub> S  | 0.18440             | 648.94              |  |
|                | C <sub>3</sub> S  | 0.58046             | 2,042.74            |  |
|                | Na <sub>2</sub> O | 0.00013             | 0.44                |  |
|                | K <sub>2</sub> O  | 0.00412             | 14.49               |  |
|                | SO <sub>3</sub>   | 0.00243             | 8.54                |  |
|                | MgO               | 0.01240             | 43.62               |  |
|                | impuritis         | 0.00967             | 34.02               |  |
|                | Total             | 1.00                | 3,519.20            |  |
|                |                   | <b>Output</b>       |                     |  |
|                |                   | Komponen            | < 23 > menuju ke EP |  |
| xmass          |                   |                     | mass (kg/jam)       |  |
| O <sub>2</sub> |                   | 0.23301             | 79,142.86           |  |
| N <sub>2</sub> |                   | 0.76699             | 260,511.92          |  |
| Total          | 1.00              | 339,654.78          |                     |  |
| 988,894.55     |                   |                     | 988,894.55          |  |

### Neraca Energi



- » temperatur bahan masuk = 1350 °C = 1623 K  
 temperatur reference = 25 °C = 298 K

### Panas Sensibel Clinker Masuk

| Komponen          | < 19 > dari output kiln |               | Cp<br>(kJ/kg.K) | ΔT (K) | Hs (kJ/jam) |
|-------------------|-------------------------|---------------|-----------------|--------|-------------|
|                   | xmass                   | mass (kg/jam) |                 |        |             |
| C <sub>3</sub> A  | 0.09306                 | 32,750.89     | 1.693           | 1,325  | 73,465,315  |
| C <sub>4</sub> AF | 0.11335                 | 39,890.72     | 3.494           | 1,325  | 184,667,440 |
| C <sub>2</sub> S  | 0.18440                 | 64,893.89     | 1.219           | 1,325  | 104,815,346 |
| C <sub>3</sub> S  | 0.58046                 | 204,273.66    | 1.165           | 1,325  | 315,419,345 |
| Na <sub>2</sub> O | 0.00013                 | 43.99         | 1.622           | 1,325  | 94,557      |
| K <sub>2</sub> O  | 0.00412                 | 1,448.88      | 1.476           | 1,325  | 2,834,217   |
| SO <sub>3</sub>   | 0.00243                 | 853.85        | 1.002           | 1,325  | 1,133,728   |
| MgO               | 0.01240                 | 4,362.19      | 1.321           | 1,325  | 7,635,195   |

|           |         |            |       |       |             |
|-----------|---------|------------|-------|-------|-------------|
| impuritis | 0.00967 | 3,401.69   | 1.000 | 1,325 | 4,507,241   |
| Total     | 1.00    | 351,919.77 |       |       | 694,572,383 |

» temperatur udara masuk = 30 °C = 303 K  
 temperatur reference = 25 °C = 298 K

#### Panas Sensibel Udara Masuk

| Komponen       | < 28 > udara masuk |               | Cp<br>(kJ/kg.K) | ΔT (K) | Hs (kJ/jam)  |
|----------------|--------------------|---------------|-----------------|--------|--------------|
|                | xmass              | mass (kg/jam) |                 |        |              |
| O <sub>2</sub> | 0.23301            | 148,421.31    | 0.916           | 5      | 679,678.01   |
| N <sub>2</sub> | 0.76699            | 488,553.47    | 1.024           | 5      | 2,500,554.23 |
| Total          | 1.00               | 636,974.78    |                 |        | 3,180,232.24 |

» temperatur udara tersier = 800 °C = 1073 K  
 temperatur reference = 25 °C = 298 K

#### Panas Sensibel Udara Tersier

| Komponen       | < 21 > udara tersier |               | Cp<br>(kJ/kg.K) | ΔT (K) | Hs (kJ/jam)  |
|----------------|----------------------|---------------|-----------------|--------|--------------|
|                | xmass                | mass (kg/jam) |                 |        |              |
| O <sub>2</sub> | 0.23301              | 45,794.56     | 1.03763         | 775    | 36,826,334.9 |
| N <sub>2</sub> | 0.76699              | 150,740.44    | 1.11294         | 775    | 130,018,246  |
| Total          | 1.00                 | 196,535.00    |                 |        | 166,844,581  |

» temperatur udara sekunder = 1,100 °C = 1,373 K  
 temperatur reference = 25 °C = 298 K

#### Panas Sensibel Udara Sekunder

| Komponen       | < 20 > udara sekunder |               | Cp<br>(kJ/kg.K) | ΔT (K) | Hs (kJ/jam)  |
|----------------|-----------------------|---------------|-----------------|--------|--------------|
|                | xmass                 | mass (kg/jam) |                 |        |              |
| O <sub>2</sub> | 0.23301               | 23,483.88     | 1.05018         | 1,075  | 26,512,050.9 |
| N <sub>2</sub> | 0.76699               | 77,301.12     | 1.12215         | 1,075  | 93,249,009.4 |
| Total          | 1.00                  | 100,785.01    |                 |        | 119,761,060  |

» temperatur debu *clinker* = 200 °C = 473 K  
 temperatur reference = 25 °C = 298 K

#### Panas Sensibel Debu Clinker ke EP

| Komponen          | < 23 > menuju ke EP |               | Cp<br>(kJ/kg.K) | ΔT (K) | Hs (kJ/jam) |
|-------------------|---------------------|---------------|-----------------|--------|-------------|
|                   | xmass               | mass (kg/jam) |                 |        |             |
| C <sub>3</sub> A  | 0.09306             | 327.51        | 0.777           | 175    | 44,540.61   |
| C <sub>4</sub> AF | 0.11335             | 398.91        | 3.314           | 175    | 231,380.56  |
| C <sub>2</sub> S  | 0.18440             | 648.94        | 0.905           | 175    | 102,826.14  |
| C <sub>3</sub> S  | 0.58046             | 2,042.74      | 0.897           | 175    | 320,491.07  |
| Na <sub>2</sub> O | 0.00013             | 0.44          | 1.273           | 175    | 98.04       |
| K <sub>2</sub> O  | 0.00412             | 14.49         | 0.990           | 175    | 2,510.64    |
| SO <sub>3</sub>   | 0.00243             | 8.54          | 0.759           | 175    | 1,134.00    |
| MgO               | 0.01240             | 43.62         | 1.078           | 175    | 8,231.53    |

|                |                     |               |                 |                |              |
|----------------|---------------------|---------------|-----------------|----------------|--------------|
| impuritis      | 0.00967             | 34.02         | 1.000           | 175            | 5,952.96     |
| Total          | 1.00                | 3,519.20      |                 |                | 717,165.56   |
| Komponen       | < 23 > menuju ke EP |               | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | Hs (kJ/jam)  |
|                | xmass               | mass (kg/jam) |                 |                |              |
| O <sub>2</sub> | 0.23301             | 79,142.86     | 0.93470         | 175            | 12,945,658.9 |
| N <sub>2</sub> | 0.76699             | 260,511.92    | 1.03746         | 175            | 47,297,530.6 |
| Total          | 1.00                | 339,654.78    |                 |                | 60,243,189.4 |
| Total          |                     |               |                 |                | 60,960,355.0 |

- » Neraca energi *clinker* keluar *Cooler*  
 temperatur *clinker* keluar = 121 °C = 394 K  
 temperatur reference = 25 °C = 298 K

#### Panas Sensibel Clinker Keluar Cooler

| Komponen          | < 29 > ke roller crusher |               | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | Hs (kJ/jam)  |
|-------------------|--------------------------|---------------|-----------------|----------------|--------------|
|                   | xmass                    | mass (kg/jam) |                 |                |              |
| C <sub>3</sub> A  | 0.09306                  | 32,423.38     | 0.708           | 96             | 2,202,448.1  |
| C <sub>4</sub> AF | 0.11335                  | 39,491.81     | 3.309           | 96             | 12,546,803.3 |
| C <sub>2</sub> S  | 0.18440                  | 64,244.95     | 0.897           | 96             | 5,534,754.0  |
| C <sub>3</sub> S  | 0.58046                  | 202,230.93    | 0.878           | 96             | 17,053,814.9 |
| Na <sub>2</sub> O | 0.00013                  | 43.55         | 1.246           | 96             | 5,208.7      |
| K <sub>2</sub> O  | 0.00412                  | 1,434.39      | 0.982           | 96             | 135,174.0    |
| SO <sub>3</sub>   | 0.00243                  | 845.31        | 0.738           | 96             | 59,909.5     |
| MgO               | 0.01240                  | 4,318.57      | 1.059           | 96             | 439,074.4    |
| impuritis         | 0.00967                  | 3,367.67      | 1.000           | 96             | 323,296.8    |
| Total             | 1.00                     | 348,400.57    |                 |                | 38,300,483.6 |

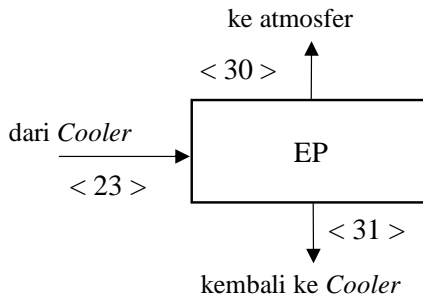
$$\begin{aligned}
 Q_{\text{loss}} &= (\Sigma H_s \text{ input} - \Sigma H_s \text{ output}) \\
 &= 697,752,615.5 - 385,866,479.9 \\
 &= 311,886,135.6 \text{ kJ/jam}
 \end{aligned}$$

#### Tabel Neraca Energi Cooler

| H input   |               | H output  |               |
|-----------|---------------|-----------|---------------|
| Hs < 19 > | 694,572,383.2 | Hs < 21 > | 166,844,580.9 |
| Hs < 28 > | 3,180,232.2   | Hs < 20 > | 119,761,060.3 |
|           |               | Hs < 23 > | 60,960,355.0  |
|           |               | Hs < 29 > | 38,300,483.6  |
|           |               | Q loss    | 311,886,135.6 |
| Total     | 697,752,615.5 | Total     | 697,752,615.5 |

## EP (ELECTROSTATIC PRECIPITATOR)

### Neraca Massa



Asumsi :

1. debu yang dibuang langsung ke atmosfer / lingkungan sebesar 0.5%

Massa debu yang dibuang langsung ke atmosfer :

$$\begin{aligned} C_3A &= 0.5\% \times \text{ouput Cooler yang masuk ke EP} \\ &= 1.64 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} C_4AF &= 0.5\% \times \text{ouput Cooler yang masuk ke EP} \\ &= 1.99 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} C_2S &= 0.5\% \times \text{ouput Cooler yang masuk ke EP} \\ &= 3.24 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} C_3S &= 0.5\% \times \text{ouput Cooler yang masuk ke EP} \\ &= 10.21 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} Na_2O &= 0.5\% \times \text{ouput Cooler yang masuk ke EP} \\ &= 0.002 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} K_2O &= 0.5\% \times \text{ouput Cooler yang masuk ke EP} \\ &= 0.072 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} SO_3 &= 0.5\% \times \text{ouput Cooler yang masuk ke EP} \\ &= 0.043 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} MgO &= 0.5\% \times \text{ouput Cooler yang masuk ke EP} \\ &= 0.218 \text{ kg/jam} \end{aligned}$$

$$\begin{aligned} \text{imprtis} &= 0.5\% \times \text{ouput Cooler yang masuk ke EP} \\ &= 0.170 \text{ kg/jam} \end{aligned}$$



### Neraca Massa EP

| Input             |                           |               | Output            |                    |               |
|-------------------|---------------------------|---------------|-------------------|--------------------|---------------|
| Komponen          | < 23 > dari output cooler |               | Komponen          | < 30 > ke atmosfer |               |
|                   | xmass                     | mass (kg/jam) |                   | xmass              | mass (kg/jam) |
| C <sub>3</sub> A  | 0.09306                   | 327.51        | C <sub>3</sub> A  | 0.0930635          | 1.64          |
| C <sub>4</sub> AF | 0.11335                   | 398.91        | C <sub>4</sub> AF | 0.1133518          | 1.99          |
| C <sub>2</sub> S  | 0.18440                   | 648.94        | C <sub>2</sub> S  | 0.1843997          | 3.24          |
| C <sub>3</sub> S  | 0.58046                   | 2,042.74      | C <sub>3</sub> S  | 0.5804552          | 10.21         |
| Na <sub>2</sub> O | 0.00013                   | 0.44          | Na <sub>2</sub> O | 0.000125           | 0.00          |
| K <sub>2</sub> O  | 0.00412                   | 14.49         | K <sub>2</sub> O  | 0.0041171          | 0.07          |
| SO <sub>3</sub>   | 0.00243                   | 8.54          | SO <sub>3</sub>   | 0.0024263          | 0.04          |
| MgO               | 0.01240                   | 43.62         | MgO               | 0.0123954          | 0.22          |
| impuritis         | 0.00967                   | 34.02         | impuritis         | 0.0096661          | 0.17          |
| Total             | 1.00                      | 3,519.20      | Total             | 1.00               | 17.60         |

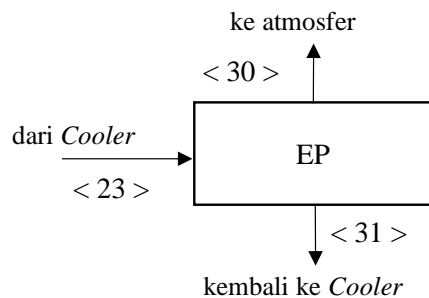
  

| Output            |                          |               |
|-------------------|--------------------------|---------------|
| Komponen          | < 31 > kembali ke cooler |               |
|                   | xmass                    | mass (kg/jam) |
| C <sub>3</sub> A  | 0.09306                  | 325.87        |
| C <sub>4</sub> AF | 0.11335                  | 396.91        |
| C <sub>2</sub> S  | 0.18440                  | 645.69        |
| C <sub>3</sub> S  | 0.58046                  | 2,032.52      |
| Na <sub>2</sub> O | 0.00013                  | 0.44          |
| K <sub>2</sub> O  | 0.00412                  | 14.42         |
| SO <sub>3</sub>   | 0.00243                  | 8.50          |
| MgO               | 0.01240                  | 43.40         |
| impuritis         | 0.00967                  | 33.85         |
| Total             | 1.00                     | 3,501.60      |

|           |           |
|-----------|-----------|
| 3,519.198 | 3,519.198 |
|-----------|-----------|

### Neraca Energi EP



Asumsi:

1. ada panas yang hilang ( $Q_{loss} \neq 0$ )
2. debu clinker yang di recycle kembali menuju Cooler

sebesar 96%

**Panas Sensibel Masuk EP**

| Komponen          | < 23 > dari cooler |               | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | Hs (kJ/jam) |
|-------------------|--------------------|---------------|-----------------|----------------|-------------|
|                   | xmass              | mass (kg/jam) |                 |                |             |
| C <sub>3</sub> A  | 0.09306            | 327.51        | 0.777           | 175            | 44,540.61   |
| C <sub>4</sub> AF | 0.11335            | 398.91        | 3.314           | 175            | 231,380.56  |
| C <sub>2</sub> S  | 0.18440            | 648.94        | 0.905           | 175            | 102,826.14  |
| C <sub>3</sub> S  | 0.58046            | 2,042.74      | 0.897           | 175            | 320,491.07  |
| Na <sub>2</sub> O | 0.00013            | 0.44          | 1.273           | 175            | 98.04       |
| K <sub>2</sub> O  | 0.00412            | 14.49         | 0.990           | 175            | 2,510.64    |
| SO <sub>3</sub>   | 0.00243            | 8.54          | 0.759           | 175            | 1,134.00    |
| MgO               | 0.01240            | 43.62         | 1.078           | 175            | 8,231.53    |
| impuritis         | 0.00967            | 34.02         | 1.000           | 175            | 5,952.96    |
| Total             | 1.00               | 3,519.20      |                 |                | 717,165.56  |

**Panas Sensibel Keluar Atmosfer**

| Komponen          | < 30 > ke atmosfer |               | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | Hs (kJ/jam) |
|-------------------|--------------------|---------------|-----------------|----------------|-------------|
|                   | xmass              | mass (kg/jam) |                 |                |             |
| C <sub>3</sub> A  | 0.09306            | 1.64          | 0.777           | 100            | 127.26      |
| C <sub>4</sub> AF | 0.11335            | 1.99          | 3.314           | 100            | 661.09      |
| C <sub>2</sub> S  | 0.18440            | 3.24          | 0.905           | 100            | 293.79      |
| C <sub>3</sub> S  | 0.58046            | 10.21         | 0.897           | 100            | 915.69      |
| Na <sub>2</sub> O | 0.00013            | 0.00          | 1.273           | 100            | 0.28        |
| K <sub>2</sub> O  | 0.00412            | 0.07          | 0.990           | 100            | 7.17        |
| SO <sub>3</sub>   | 0.00243            | 0.04          | 0.759           | 100            | 3.24        |
| MgO               | 0.01240            | 0.22          | 1.078           | 100            | 23.52       |
| impuritis         | 0.00967            | 0.17          | 1.000           | 100            | 17.01       |
| Total             | 1.00               | 17.60         |                 |                | 2,049.04    |

**Panas Sensibel kembali ke cooler**

| Komponen          | < 31 > kembali ke cooler |               | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | Hs (kJ/jam) |
|-------------------|--------------------------|---------------|-----------------|----------------|-------------|
|                   | xmass                    | mass (kg/jam) |                 |                |             |
| C <sub>3</sub> A  | 0.09306                  | 325.87        | 0.777           | 96             | 24,311.54   |
| C <sub>4</sub> AF | 0.11335                  | 396.91        | 3.314           | 96             | 126,294.12  |
| C <sub>2</sub> S  | 0.18440                  | 645.69        | 0.905           | 96             | 56,125.45   |
| C <sub>3</sub> S  | 0.58046                  | 2,032.52      | 0.897           | 96             | 174,933.19  |
| Na <sub>2</sub> O | 0.00013                  | 0.44          | 1.273           | 96             | 53.51       |
| K <sub>2</sub> O  | 0.00412                  | 14.42         | 0.990           | 96             | 1,370.38    |
| SO <sub>3</sub>   | 0.00243                  | 8.50          | 0.759           | 96             | 618.97      |
| MgO               | 0.01240                  | 43.40         | 1.078           | 96             | 4,493.01    |
| impuritis         | 0.00967                  | 33.85         | 1.000           | 96             | 3,249.30    |
| Total             | 1.00                     | 3,501.60      |                 |                | 388,200.16  |

$$\begin{aligned}
 Q_{\text{loss}} &= (\Sigma H_{\text{s input}} - \Sigma H_{\text{s output}}) \\
 &= 717,165.56 - 390,249.20 \\
 &= 326,916.36 \text{ kJ/jam}
 \end{aligned}$$

**Tabel Neraca Energi EP**

| H input   |            | H output  |            |
|-----------|------------|-----------|------------|
| Hs < 23 > | 717,165.56 | Hs < 30 > | 2,049.04   |
|           |            | Hs < 31 > | 388,200.16 |
|           |            | Qloss     | 326,916.36 |
| Total     | 717,165.56 | Total     | 717,165.56 |



**LAMPIRAN G**  
**PERHITUNGAN ENTALPI, ENTROPI DAN EKSERGI RKC-2**

**Rotary Kiln**

A. Steam Inlet

Stream 18 Produk Keluar *Suspension Preheater* ( masuk ke kiln)

| Komponen                        | < 18 > ke Kiln |                | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | T (K) | T Ref<br>(K) | Hs (kJ/jam) | $\Delta S$ (kJ/kg.K) | $E^{PH}$ (kJ/jam) | $E^{CH}$ (kJ/jam) |
|---------------------------------|----------------|----------------|-----------------|----------------|-------|--------------|-------------|----------------------|-------------------|-------------------|
|                                 | xmass          | massa (kg/jam) |                 |                |       |              |             |                      |                   |                   |
| CaCO <sub>3</sub>               | 0.1119         | 41,346.09      | 1.3461          | 840            | 1138  | 298          | 46,751,105  | 74,575.48            | 24,527,613        | 6,739,413         |
| CaO                             | 0.5639         | 208,384.29     | 1.1282          | 840            | 1138  | 298          | 197,484,074 | 315,018.63           | 103,608,522       | 473,702,150       |
| Fe <sub>2</sub> O <sub>3</sub>  | 0.0355         | 13,132.75      | 1.08694         | 840            | 1138  | 298          | 11,990,602  | 19,126.93            | 6,290,779         | 1,354,315         |
| SiO <sub>2</sub>                | 0.2067         | 76,393.63      | 1.17517         | 840            | 1138  | 298          | 75,411,262  | 120,293.00           | 39,563,947        | 10,440,463        |
| Al <sub>2</sub> O <sub>3</sub>  | 0.0561         | 20,744.69      | 1.28201         | 840            | 1138  | 298          | 22,339,646  | 35,635.30            | 11,720,326        | 40,769,410        |
| MgO                             | 0.0118         | 4,362.19       | 1.24205         | 840            | 1138  | 298          | 4,551,167   | 7,259.84             | 2,387,735         | 6,397,160         |
| K <sub>2</sub> O                | 0.0039         | 1,448.88       | 1.23892         | 840            | 1138  | 298          | 1,507,838   | 2,405.24             | 791,076           | 10,882,429        |
| Na <sub>2</sub> O               | 0.0001         | 43.99          | 1.54876         | 840            | 1138  | 298          | 57,229      | 91.29                | 30,025            | 210,159           |
| SO <sub>3</sub>                 | 0.0023         | 853.85         | 0.9593          | 840            | 1138  | 298          | 688,040     | 1,097.53             | 360,975           | 2,658,661         |
| impuritis                       | 0.0064         | 2,381.18       | 1               | 840            | 1138  | 298          | 2,000,195   | 3,190.63             | 1,049,387         | 2,381,184         |
| H <sub>2</sub> O <sub>(l)</sub> | 0.0013         | 472.07         | 4.54782         | 840            | 1138  | 298          | 1,803,388   | 2,876.69             | 946,134           | 23,603            |
| Total                           | 1              | 369,563.61     |                 |                |       |              | 364,584,546 | 581,570.57           | 191,276,517       | 555,558,946       |

Stream 51 Batubara

| Komponen                        | < 51 > batubara |                | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | T (K) | T Ref<br>(K) | Hs (kJ/jam) | $\Delta S$ (kJ/kg.K) | $E^{PH}$ (kJ/jam) | $E^{CH}$ (kJ/jam) |
|---------------------------------|-----------------|----------------|-----------------|----------------|-------|--------------|-------------|----------------------|-------------------|-------------------|
|                                 | xmass           | massa (kg/jam) |                 |                |       |              |             |                      |                   |                   |
| C                               | 0.5343          | 9,016.31       | 0.8365          | 30             | 328   | 298          | 226,272.61  | 723.47               | 10,678.59         | 307,959,667       |
| H                               | 0.0415          | 700.31         | 14.397          | 30             | 328   | 298          | 302,463.74  | 967.08               | 14,274.31         | 232,013,531       |
| N                               | 0.0087          | 146.81         | 1.0255          | 30             | 328   | 298          | 4,516.67    | 14.44                | 213.16            | 7,550             |
| O                               | 0.2324          | 3,921.75       | 0.9184          | 30             | 328   | 298          | 108,050.52  | 345.47               | 5,099.28          | 57,282,061        |
| S                               | 0.0018          | 30.38          | 0.7450          | 30             | 328   | 298          | 678.91      | 2.17                 | 32.04             | 578,643.75        |
| H <sub>2</sub> O <sub>(l)</sub> | 0.1488          | 2,511.00       | 4.2019          | 30             | 328   | 298          | 316,526.74  | 1,012.04             | 14,937.99         | 125,550.00        |
| Ash                             | 0.0325          | 548.44         | 1.000           | 30             | 328   | 298          | 16,453.13   | 52.61                | 776.48            | 548,437.50        |
| Total                           | 1               | 16,875.00      |                 |                |       |              | 974,962.33  | 3,117.28             | 46,011.84         | 598,515,441       |
| Komponen                        | < 51 > batubara |                | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | T (K) | T Ref<br>(K) | Hs (kJ/jam) | $\Delta S$ (kJ/kg.K) | $E^{PH}$ (kJ/jam) | $E^{CH}$ (kJ/jam) |
|                                 | xmass           | massa (kg/jam) |                 |                |       |              |             |                      |                   |                   |
| O <sub>2</sub>                  | 0.233           | 983.01         | 0.9184          | 30             | 328   | 298          | 27,083.50   | 86.60                | 1,278.16          | 121,954.64        |
| N <sub>2</sub>                  | 0.767           | 3,235.74       | 1.0255          | 30             | 328   | 298          | 99,547.28   | 318.29               | 4,697.98          | 79,737.89         |
| Total                           | 1               | 4,218.75       |                 |                |       |              | 126,630.78  | 404.88               | 5,976.14          | 201,692.53        |

Stream 20 Udara Sekunder

| Komponen       | < 20 > Udara Sekunder |                | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | T (K) | T Ref<br>(K) | Hs (kJ/jam) | $\Delta S$ (kJ/kg.K) | $E^{PH}$ (kJ/jam) | $E^{CH}$ (kJ/jam) |
|----------------|-----------------------|----------------|-----------------|----------------|-------|--------------|-------------|----------------------|-------------------|-------------------|
|                | xmass                 | massa (kg/jam) |                 |                |       |              |             |                      |                   |                   |
| O <sub>2</sub> | 0.233                 | 23,483.88      | 1.0502          | 1075           | 1,373 | 298          | 26,512,051  | 37,675.72            | 15,284,687        | 2,913,469.5       |
| N <sub>2</sub> | 0.767                 | 77,301.12      | 1.1221          | 1075           | 1,373 | 298          | 93,249,009  | 132,514.21           | 53,759,775        | 1,904,920.5       |
| Total          | 1                     | 100,785.01     |                 |                |       |              | 119,761,060 | 170,189.93           | 69,044,462        | 4,818,390         |

Stream 22 Udara Primer

| Komponen       | < 22 > Udara Primer |                | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | T (K) | T Ref<br>(K) | Hs (kJ/jam) | $\Delta S$ (kJ/kg.K) | $E^{PH}$ (kJ/jam) | $E^{CH}$ (kJ/jam) |
|----------------|---------------------|----------------|-----------------|----------------|-------|--------------|-------------|----------------------|-------------------|-------------------|
|                | xmass               | massa (kg/jam) |                 |                |       |              |             |                      |                   |                   |
| O <sub>2</sub> | 0.233               | 2,275.56       | 0.9159          | 5              | 303   | 298          | 10,420.65   | 34.68                | 86.46             | 282,311.26        |
| N <sub>2</sub> | 0.767               | 7,490.37       | 1.0237          | 5              | 303   | 298          | 38,337.84   | 127.58               | 318.07            | 184,584.22        |
| Total          | 1                   | 9,765.93       |                 |                |       |              | 48,758.49   | 162.26               | 404.53            | 466,895.48        |

B. Stream Output

Stream 17 Keluar ke Kalsiner

| Komponen            | < 17 > ke Kalsiner |                | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | T (K) | T Ref<br>(K) | Hs (kJ/jam) | $\Delta S$ (kJ/kg.K) | $E^{PH}$ (kJ/jam) | $E^{CH}$ (kJ/jam) |
|---------------------|--------------------|----------------|-----------------|----------------|-------|--------------|-------------|----------------------|-------------------|-------------------|
|                     | xmass              | massa (kg/jam) |                 |                |       |              |             |                      |                   |                   |
| CO <sub>2</sub>     | 0.3433             | 51,252.09      | 1.1339          | 975            | 1273  | 298          | 56,660,017  | 84,382.06            | 31,514,164        | 22,690,699        |
| H <sub>2</sub> O(g) | 0.0590             | 8,813.81       | 2.1338          | 975            | 1273  | 298          | 18,337,064  | 27,308.84            | 10,199,031        | 4,651,734         |
| NO <sub>2</sub>     | 0.0032             | 482.38         | 1.167           | 975            | 1273  | 298          | 548,676     | 817.13               | 305,172           | 583,055.36        |
| SO <sub>2</sub>     | 0.0004             | 60.75          | 1.0376          | 975            | 1273  | 298          | 61,460      | 91.53                | 34,184            | 297,485.16        |
| O <sub>2</sub>      | 0.0044             | 652.25         | 1.1129          | 975            | 1273  | 298          | 707,774     | 1,054.07             | 393,662           | 80,920.37         |
| N <sub>2</sub>      | 0.5896             | 88,027.24      | 0.8647          | 975            | 1273  | 298          | 74,212,386  | 110,522.27           | 41,276,750        | 2,169,242.6       |
| Total               | 1                  | 149,288.53     |                 |                |       |              | 150,527,377 | 224,175.89           | 83,722,963        | 30,473,137        |

Stream 19 Produk Keluar Klinker

| Komponen          | < 19 > menuju ke Cooler |                | Cp<br>(kJ/kg.K) | $\Delta T$ (K) | T (K) | T Ref<br>(K) | Hs (kJ/jam) | $\Delta S$ (kJ/kg.K) | $E^{PH}$ (kJ/jam) | $E^{CH}$ (kJ/jam) |
|-------------------|-------------------------|----------------|-----------------|----------------|-------|--------------|-------------|----------------------|-------------------|-------------------|
|                   | xmass                   | massa (kg/jam) |                 |                |       |              |             |                      |                   |                   |
| C <sub>3</sub> A  | 0.0931                  | 32,750.89      | 1.640           | 1225           | 1523  | 298          | 65,804,309  | 87,632.21            | 39,689,911        | 46,409,228        |
| C <sub>4</sub> AF | 0.1134                  | 39,890.72      | 3.479           | 1225           | 1523  | 298          | 169,993,436 | 226,381.84           | 102,531,649       | 17,417,307        |
| C <sub>2</sub> S  | 0.1844                  | 64,893.89      | 1.192           | 1225           | 1523  | 298          | 94,774,288  | 126,211.80           | 57,163,172        | 49,009,977        |
| C <sub>3</sub> S  | 0.5805                  | 204,273.66     | 1.149           | 1225           | 1523  | 298          | 287,419,522 | 382,759.24           | 173,357,267       | 36,464,641        |
| Na <sub>2</sub> O | 0.0001                  | 43.99          | 1.627           | 1225           | 1523  | 298          | 87,681      | 116.77               | 52,885            | 210,159           |
| K <sub>2</sub> O  | 0.0041                  | 1,448.88       | 1.433           | 1225           | 1523  | 298          | 2,543,490   | 3,387.19             | 1,534,108         | 10,882,429        |
| SO <sub>3</sub>   | 0.0024                  | 853.85         | 0.997           | 1225           | 1523  | 298          | 1,043,262   | 1,389.32             | 629,244           | 2,658,661         |
| MgO               | 0.0124                  | 4,362.19       | 1.307           | 1225           | 1523  | 298          | 6,986,593   | 9,304.11             | 4,213,968         | 6,397,160         |
| impuritis         | 0.0097                  | 3,401.69       | 1.00            | 1225           | 1523  | 298          | 4,167,072   | 5,549.33             | 2,513,372         | 3,401,692         |
| Total             | 1                       | 351,919.77     |                 |                |       |              | 632,819,654 | 842,731.81           | 381,685,576       | 172,851,253       |

| Komponen                       | BM   |
|--------------------------------|------|
| CaCO <sub>3</sub>              | 100  |
| CaO                            | 56   |
| CO <sub>2</sub>                | 44   |
| C <sub>2</sub> S               | 172  |
| C <sub>3</sub> S               | 228  |
| C <sub>3</sub> A               | 270  |
| C <sub>4</sub> AF              | 486  |
| SiO <sub>2</sub>               | 60   |
| Al <sub>2</sub> O <sub>3</sub> | 102  |
| Fe <sub>2</sub> O <sub>3</sub> | 160  |
| MgO                            | 40.3 |
| K <sub>2</sub> O               | 55   |
| Na <sub>2</sub> O              | 62   |
| SO <sub>3</sub>                | 80   |
| impuritis                      | 1    |
| H <sub>2</sub> O (l)           | 18   |
| H <sub>2</sub> O (g)           | 18   |
| C                              | 12   |
| H                              | 1    |
| N                              | 14   |
| O                              | 16   |
| S                              | 32   |
| NO <sub>2</sub>                | 46   |
| SO <sub>2</sub>                | 64   |
| O <sub>2</sub>                 | 32   |

| Komponen                       | Standard Chemical Exergy<br>(kJ/kmol) |
|--------------------------------|---------------------------------------|
| CaCO <sub>3</sub>              | 16300                                 |
| CaO                            | 127300                                |
| CO <sub>2</sub>                | 19480                                 |
| C <sub>2</sub> S               | 129900                                |
| C <sub>3</sub> S               | 40700                                 |
| C <sub>3</sub> A               | 382600                                |
| C <sub>4</sub> AF              | 212200                                |
| SiO <sub>2</sub>               | 8200                                  |
| Al <sub>2</sub> O <sub>3</sub> | 200460                                |
| Fe <sub>2</sub> O <sub>3</sub> | 16500                                 |
| MgO                            | 59100                                 |
| K <sub>2</sub> O               | 413100                                |
| Na <sub>2</sub> O              | 296200                                |
| SO <sub>3</sub>                | 249100                                |
| impuritis                      | 1000                                  |
| H <sub>2</sub> O (l)           | 900                                   |
| H <sub>2</sub> O (g)           | 9500                                  |
| C                              | 409870                                |
| H                              | 331300                                |
| N                              | 720                                   |
| O                              | 233700                                |
| S                              | 609600                                |
| NO <sub>2</sub>                | 55600                                 |
| SO <sub>2</sub>                | 313400                                |





| Komponen       | BM |
|----------------|----|
| N <sub>2</sub> | 28 |

| Komponen       | Standard Chemical Exergy<br>(kJ/kmol) |
|----------------|---------------------------------------|
| O <sub>2</sub> | 3970                                  |
| N <sub>2</sub> | 690                                   |

Eksergi pada Rotary Kiln

$$\begin{aligned}
 \sum [Ex_{in}] &= 1,419,934,737.04 & \text{Efisiensi Eksergi} &= 0.471 \\
 \sum [Ex_{out}] &= 668,732,929 & &= 47.10 \% \\
 \sum [Ex_{dest}] &= 751,201,808.03 & \text{Eksergi Rusak} &= 0.52904 \\
 & & &= 52.90 \%
 \end{aligned}$$

