UNIVERSITAS GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

DAFTAR ISI

LEMBAR PENGESAHAN I
PERNYATAAN BEBAS PLAGIASI II
KATA PENGANTAR III
DAFTAR TABEL XXIV
DAFTAR GAMBAR XLV
INTISARI LII
ABSTRACT LIV
BAB I PENDAHULUAN 1
1.1 Latar Belakang 1
1.2 Tinjauan Pustaka 2
1.2.1 Timah Logam 99,85% dan 99,99% 2
1.2.2 *Thorium Oxide* 3
1.2.3 REE *Oxide Concentrate* 3
1.3 Pemilihan Proses 4
1.4 Analisis Pasar 5
1.4.1 Proyeksi Kebutuhan Pasar 5
1.4.2 Kapasitas Pabrik Existing 9
1.5 Penentuan Kapasitas Pabrik 9
1.5.1 Kapasitas *Tin Ingot* 9
1.5.2 Kapasitas *Rare Earth Oxide Concentrate* 10
1.5.3 Kapasitas *Thorium Oxide* 11
1.6 Penentuan Lokasi Pabrik 11
BAB II URAIAN PROSES 14
2.1 Tahap Pengambilan Bahan Baku 14
2.2 Tahap Pencucian 15
2.3 Tahap Pengonsentrasian Kasiterit 16
2.4 Tahap Pengonsentrasian Monasit dan Xenotim 16
2.5 Tahap Peleburan 16
2.6 Tahap Pemurnian Lanjut 17
2.6.1 *Eutetic-Refining* 17
2.6.2 *Pyro-Refining* 17
2.6.3 *Electro-Refining* 19
2.7 Tahap Pengolahan *Tin Slag* 21
2.8 Tahap Pengolahan *Thorium Oxide* 23

Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

2.9 Tahap Pengolahan *Rare Earth Oxide Concentrate* 24
BAB III SPESIFIKASI BAHAN DAN PRODUK 25
3.1 Spesifikasi Bahan Baku 25
3.1.1 Timah Aluvial 25
3.1.2 *Tin Slag* 25
3.2 Spesifikasi Bahan Pendukung 26
3.2.1 *Coke* (C) 26
3.2.2 Natrium Karbonat (Na_2CO_3) 26
3.2.3 *Sawdust* 27
3.2.4 Aluminium (Al) 28
3.2.5 *Sulphur* (S) 28
3.2.6 *Stannous Sulphate* ($SnSO_4$) 29
3.2.7 *Sulphuric Acid* (H_2SO_4) 29
3.2.8 *Nitric Acid* (HNO_3) 30
3.2.9 *Hexafluorosilicic Acid* (H_2SiF_6) 30
3.2.10 *Oxalic Acid* ($H_2C_2O_4$) 31
3.2.*11* *Ammonium Hydroxide* (NH_4OH) 32
3.2.12 *Sodium Hydroxide* (NaOH) 32
3.2.13 *Tri*-n-*butyl Phosphate* (TBP) 33
3.2.14 *Kerosene* 33
3.2.15 *Methane* (CH_4) 34
3.2.16 *Dodecane* ($C_{12}H_{26}$) 34
3.3 Spesifikasi Produk 35
3.3.1 *Tin Ingot* 35
3.3.2 REE *Oxide Concentrate* 36
3.3.3 *Thorium Oxide* 37
BAB IV DIAGRAM ALIR KUALITATIF, KUANTITATIF, DAN *PROCESS ENGINEERING FLOW DIAGRAM* (PEFD) 38
4.1 Diagram Alir Kualitatif 38
4.1.1 Diagram Alir Kualitatif Unit Pengonsentrasian Kapal 38
4.1.2 Diagram Alir Kualitatif Unit Pencucian 39
4.1.3 Diagram Alir Kualitatif Unit Pengonsentrasian Kasiterit 40
4.1.4 Diagram Alir Kualitatif Unit Pengonsentrasian Monasit dan Xenotim 41
4.1.5 Diagram Alir Kualitatif Unit Peleburan 42
4.1.6 Diagram Alir Kualitatif Unit Pemurnian Lanjut 43
4.1.7 Diagram Alir Kualitatif Unit Pengolahan *Tin Slag* 44
4.1.8 Diagram Alir Kualitatif Unit Pengolahan *Thorium Oxide* 45

UNIVERSITAS GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

4.1.9 Diagram Alir Kualitatif Unit Pengolahan *REE Oxide Concentrate* 46
4.2 Diagram Alir Kuanitatif 47
4.2.1 Diagram Alir Kuantitatif Unit Pengonsentrasian Kapal 47
4.2.2 Diagram Alir Kuantitatif Unit Pencucian 50
4.2.3 Diagram Alir Kuantitatif Unit Pengonsentrasian Kasiterit 52
4.2.4 Diagram Alir Kuantitatif Unit Pengonsentrasian Monasit Xenotim 54
4.2.5 Diagram Alir Kuantitatif Unit Peleburan 55
4.2.6 Diagram Alir Kuantitatif Unit Pemurnian Lanjut 59
4.2.7 Diagram Alir Kuantitatif Unit Pengolahan *Tin Slag* 66
4.2.8 Diagram Alir Kuantitatif Unit Pengolahan *Thorium Oxide* 75
4.2.9 Diagram Alir Kuantitatif Unit Pengolahan *REE Oxide Concentrate* 82
4.3 *Process Engineering Flow Diagram* 87
4.3.1 *Process Engineering Flow Diagram Plant* 1 87
4.3.2 *Process Engineering Flow Diagram Plant* 2 88
4.3.3 *Process Engineering Flow Diagram Plant* 3 89
4.3.4 *Process Engineering Flow Diagram Plant* 4 90
BAB V NERACA MASSA 91
5.1 Neraca Massa *Overall* 91
5.2 Neraca Massa per Alat 95
5.2.1 Unit Pengonsentrasian Kapal 95
5.2.2 Unit Pencucian 104
5.2.3 Unit Pengonsentrasian Darat 110
5.2.4 Unit Pengonsentrasian Monasit Xenotim 120
5.2.5 Unit Peleburan 123
5.2.6 Unit Pemurnian Lanjut 131
5.2.7 Unit Pengolahan Tin Slag 145
5.2.8 Unit Pengolahan *Thorium Oxide* 178
5.2.9 Unit Pengolahan *REE Oxide Concentrate* 207
BAB VI NERACA PANAS 221
6.1 Unit Pengonsentrasian Darat 221
6.2 Unit Pengonsentrasian Monasit Xenotim 223
6.3 Unit Peleburan 224
6.4 Unit Pemurnian Lanjut 229
6.5 Unit Pengolahan *Tin Slag* 241
6.6 Unit Pengolahan *Thorium Oxide* 256
6.7 Unit Pengolahan *REE Oxide Concentrate* 270
BAB VII SPESIFIKASI ALAT 278

UNIVERSITAS GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

7.1 Centrifuge (CF-301) 278
7.2 Centrifuge (CF-801) 278
7.3 Centrifuge (CF-802) 278
7.4 Centrifuge (CF-901) 279
7.5 Centrifuge (CF-902) 279
7.6 Centrifuge (CF-903) 279
7.7 Filter Press (FP-701) 280
7.8 Filter Press (FP-702) 280
7.9 Rotary Dryer (RD-301) 281
7.10 Rotary Dryer (RD-302) 282
7.11 Rotary Dryer (RD-401) 282
7.12 Rotary Dryer (RD-801) 283
7.13 Rotary Dryer (RD-901) 284
7.14 Rotary Vacuum Filter (RV-801) 285
7.15 Rotary Vacuum Filter (RV-802) 285
7.16 Tray Dryer (TD-701) 286
7.17 Digest Reactor (R-801) 286
7.18 Leaching Reactor (R-701) 287
7.19 Dilution Reactor (R-802) 287
7.20 Dilution Reactor (R-803) 288
7.21 Dilution Reactor (R-806) 288
7.22 Dilution Reactor (R-903) 288
7.23 Precipitation Reactor (R-804) 289
7.24 Precipitation Reactor (R-807) 289
7.25 Precipitation Reactor (R-901) 290
7.26 Precipitation Reactor (R-904) 290
7.27 Reverberatory Furnace (RF-501) 291
7.28 Reverberatory Furnace (RF-502) 291
7.29 Reverberatory Furnace (RF-701) 292
7.30 Rotary Kiln (RK-801) 293
7.31 Rotary Kiln (RK-901) 293
7.32 Mixer Settler (MS-801) 294
7.33 Mixer Settler (MS-802) 294
7.34 Mixer (MX-601) 295
7.35 Mixer (MX-701) 295
7.36 Mixer (MX-702) 296
7.37 Mixer (MX-703) 296

UNIVERSITAS
GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

7.38 Mixer (MX-801) 296
7.39 Mixer (MX-802) 297
7.40 Mixer (MX-803) 297
7.41 Crystllizer (CR-601) 298
7.42 Electric Kettle (EK-601) 298
7.43 Electric Kettle (EK-602) 298
7.44 Electric Kettle (EK-603) 299
7.45 Electric Kettle (EK-604) 299
7.46 Electric Kettle (EK-605) 300
7.47 Electrorefinning Cell (EC-601) 300
7.48 Anode Casting (AC-601) 301
7.49 Cathode Casting (CC-601) 301
7.50 Product Casting (PC-601) 302
7.51 Product Casting (PC-602) 302
7.52 Ball Mill (BM-701) 303
7.53 Ball Mill (BM-801) 303
7.54 Hammmer Crusher (HC-501) 304
7.55 Circular Vibrating Screen (CS-301) 304
7.56 Gyratory Screen (GS-701) 305
7.57 Rotary Screen (RS-101) 305
7.58 Primary Jig (PJ-101) 305
7.59 Primary Jig (PJ-102) 306
7.60 Primary Jig (PJ-103) 306
7.61 Primary Jig (PJ-201) 307
7.62 Primary Jig (PJ-202) 307
7.63 Primary Jig (PJ-301) 308
7.64 Primary Jig (PJ-302) 308
7.65 Primary Jig (PJ-303) 309
7.66 Primary Jig (PJ-304) 310
7.67 Secondary Jig (SJ-101) 310
7.68 Secondary Jig (SJ-102) 311
7.69 Secondary Jig (SJ-103) 311
7.70 Secondary Jig (SJ-104) 312
7.71 Secondary Jig (SJ-105) 312
7.72 Secondary Jig (SJ-201) 313
7.73 Secondary Jig (SJ-202) 313
7.74 Secondary Jig (SJ-203) 314

UNIVERSITAS GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

7.75 Air Table (AT-301) 314
7.76 Dry High Intensity Magnetic Separator (DHIMS-401) 315
7.77 High Tension Roll Separator (HTRS-401) 315
7.78 Air Cooling Pit (AP-501) 316
7.79 Air Cooling Pit (AP-801) 316
7.80 Air Cooling Pit (AP-901) 316
7.81 Holding Pot (HP-601) 317
7.82 Settling Pond (SL-101) 317
7.83 Storage Box (SL-102) 317
7.84 Storage Box (SL-103) 318
7.85 Settling Pond (SL-201) 318
7.86 Settling Pond (SL-301) 318
7.87 Product Storage (PS-801) 319
7.88 Product Storage (PS-901) 319
7.89 Quenching Tank (QT-701) 319
7.90 Storage Tank (ST-501) 320
7.91 Storage Tank (ST-502) 320
7.92 Storage Tank (ST-601) 321
7.93 Storage Tank (ST-603) 321
7.94 Storage Tank (ST-604) 322
7.95 Storage Tank (ST-605) 322
7.96 Storage Tank (ST-606) 322
7.97 Storage Tank (ST-701) 323
7.98 Storage Tank (ST-702) 323
7.99 Storage Tank (ST-801) 324
7.100 Storage Tank (ST-802) 324
7.101 Storage Tank (ST-803) 324
7.102 Storage Tank (ST-804) 325
7.103 Storage Tank (ST-805) 325
7.104 Storage Tank (ST-806) 326
7.105 Storage Tank (ST-901) 326
7.106 Storage Tank (ST-902) 327
7.107 Ladle (LL-501) 327
7.108 Launder (LD-501) 327
7.109 Launder (LD-502) 328
7.110 Launder (LD-503) 328
7.111 Belt Conveyor (BC-101) 329

Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

7.112 Belt Conveyor (BC-102) 329
7.113 Belt Conveyor (BC-103) 330
7.114 Belt Conveyor (BC-104) 330
7.115 Belt Conveyor (BC-301) 331
7.116 Belt Conveyor (BC-302) 331
7.117 Belt Conveyor (BC-303) 331
7.118 Belt Conveyor (BC-304) 332
7.119 Belt Conveyor (BC-305) 332
7.120 Belt Conveyor (BC-306) 333
7.121 Belt Conveyor (BC-307) 333
7.122 Belt Conveyor (BC-308) 334
7.123 Belt Conveyor (BC-401) 334
7.124 Belt Conveyor (BC-402) 334
7.125 Belt Conveyor (BC-403) 335
7.126 Belt Conveyor (BC-404) 335
7.127 Belt Conveyor (BC-405) 336
7.128 Belt Conveyor (BC-406) 336
7.129 Belt Conveyor (BC-407) 337
7.130 Belt Conveyor (BC-501) 337
7.131 Belt Conveyor (BC-502) 337
7.132 Belt Conveyor (BC-503) 338
7.133 Belt Conveyor (BC-504) 338
7.134 Belt Conveyor (BC-505) 339
7.135 Belt Conveyor (BC-701) 339
7.136 Belt Conveyor (BC-702) 340
7.137 Belt Conveyor (BC-703) 340
7.138 Belt Conveyor (BC-704) 340
7.139 Belt Conveyor (BC-801) 341
7.140 Belt Conveyor (BC-802) 341
7.141 Belt Conveyor (BC-901) 342
7.142 Belt Conveyor (BC-902) 342
7.143 Bucket Elevator (BE-401) 343
7.144 Bucket Elevator (BE-402) 343
7.145 Bucket Elevator (BE-601) 344
7.146 Bucket Elevator (BE-801) 344
7.147 Flight Conveyor (FC-801) 345
7.148 Flight Conveyor (FC-802) 345

UNIVERSITAS
GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

7.149 Flight Conveyor (FC-901) 345
7.150 Flight Conveyor (FC-902) 346
7.151 Screw Conveyor (SC-301) 346
7.152 Screw Conveyor (SC-302) 347
7.153 Screw Conveyor (SC-303) 347
7.154 Screw Conveyor (SC-304) 348
7.155 Screw Conveyor (SC-305) 348
7.156 Screw Conveyor (SC-601) 349
7.157 Screw Conveyor (SC-701) 349
7.158 Screw Conveyor (SC-702) 350
7.159 Screw Conveyor (SC-703) 350
7.160 Screw Conveyor (SC-801) 351
7.161 Screw Conveyor (SC-901) 351
7.162 Water Pump (P-101) 352
7.163 Water Pump (P-102) 352
7.164 Water Pump (P-103) 353
7.165 Water Pump (P-104) 353
7.166 Water Pump (P-105) 354
7.167 Water Pump (P-106) 354
7.168 Water Pump (P-107) 355
7.169 Water Pump (P-108) 355
7.170 Water Pump (P-201) 356
7.171 Water Pump (P-202) 356
7.172 Water Pump (P-203) 357
7.173 Water Pump (P-204) 357
7.174 Water Pump (P-205) 358
7.175 Water Pump (P-301) 358
7.176 Water Pump (P-302) 359
7.177 Water Pump (P-303) 359
7.178 Water Pump (P-304) 360
7.179 Liquid Pump (P-601) 360
7.180 Water Pump (P-602) 361
7.181 Water Pump (P-603) 361
7.182 Water Pump (P-604) 362
7.183 Water Pump (P-701) 362
7.184 Water Pump (P-702) 363
7.185 Water Pump (P-703) 363

Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

7.186 Water Pump (P-704) 364
7.187 Water Pump (P-705) 364
7.188 Liquid Pump (P-706) 365
7.189 Water Pump (P-707) 365
7.190 Liquid Pump (P-708) 366
7.191 Liquid Pump (P-801) 366
7.192 Liquid Pump (P-802) 367
7.193 Liquid Pump (P-803) 367
7.194 Liquid Pump (P-804) 368
7.195 Liquid Pump (P-805) 368
7.196 Liquid Pump (P-806) 369
7.197 Liquid Pump (P-807) 369
7.198 Liquid Pump (P-808) 370
7.199 Liquid Pump (P-809) 370
7.200 Liquid Pump (P-810) 371
7.201 Liquid Pump (P-811) 371
7.202 Liquid Pump (P-812) 372
7.203 Liquid Pump (P-813) 372
7.204 Liquid Pump (P-814) 373
7.205 Liquid Pump (P-815) 373
7.206 Liquid Pump (P-816) 374
7.207 Slurry Pump (SP-101) 374
7.208 Slurry Pump (SP-102) 375
7.209 Slurry Pump (SP-103) 375
7.210 Slurry Pump (SP-104) 376
7.211 Slurry Pump (SP-105) 376
7.212 Slurry Pump (SP-106) 377
7.213 Slurry Pump (SP-107) 377
7.214 Slurry Pump (SP-108) 378
7.215 Slurry Pump (SP-109) 378
7.216 Slurry Pump (SP-110) 379
7.217 Slurry Pump (SP-111) 379
7.218 Slurry Pump (SP-112) 380
7.219 Slurry Pump (SP-113) 380
7.220 Slurry Pump (SP-114) 381
7.221 Slurry Pump (SP-115) 381
7.222 Slurry Pump (SP-201) 382

Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

7.223 Slurry Pump (SP-202) 382
7.224 Slurry Pump (SP-203) 383
7.225 Slurry Pump (SP-204) 383
7.226 Slurry Pump (SP-205) 384
7.227 Slurry Pump (SP-206) 384
7.228 Slurry Pump (SP-207) 385
7.229 Slurry Pump (SP-208) 385
7.230 Slurry Pump (SP-209) 386
7.231 Slurry Pump (SP-210) 386
7.232 Slurry Pump (SP-211) 387
7.233 Slurry Pump (SP-212) 387
7.234 Slurry Pump (SP-301) 388
7.235 Slurry Pump (SP-302) 388
7.236 Slurry Pump (SP-303) 389
7.237 Slurry Pump (SP-304) 389
7.238 Slurry Pump (SP-305) 390
7.239 Slurry Pump (SP-701) 390
7.240 Slurry Pump (SP-702) 391
7.241 Slurry Pump (SP-703) 391
7.242 Slurry Pump (SP-704) 392
7.243 Slurry Pump (SP-705) 392
7.244 Slurry Pump (SP-801) 393
7.245 Slurry Pump (SP-802) 393
7.246 Slurry Pump (SP-803) 394
7.247 Slurry Pump (SP-804) 394
7.248 Slurry Pump (SP-805) 395
7.249 Kapal Keruk 395
7.250 Borehole Mining 395
BAB VIII UTILITAS 396
8.1 Unit Penyedia dan Pengolahan Air 396
8.1.1 Kebutuhan Air Pabrik 396
8.1.2 Sumber Air 398
8.1.3 Proses Pengolahan Air 399
8.1.4 Pengolahan Air Resirkulasi Pengonsentrasian 404
8.2 Unit Pembangkit *Steam* 412
8.2.1 Kebutuhan *Steam* pada *Plant* Pengolahan *Thorium* 412
8.2.2 Persiapan *Boiler Feed Water* (BFW) dan Perhitungan Dearasi 413

Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

8.2.3 Perhitungan *Boiler* 419
8.3 Unit Penyedia Udara 420
8.3.1 Udara Proses 422
8.3.2 Udara Instrumentasi 423
8.3.3 Perhitungan Alat Proses Penyedia Udara 424
8.4 Unit Pembangkit Listrik 431
8.4.1 Kebutuhan Listrik 431
8.5 Unit Pengolahan Limbah 432
8.5.1 Limbah Gas 433
8.5.2 Limbah Cair 439
8.5.3 Limbah Padat 445
8.6 Unit Refrigerasi 449
BAB IX TATA LETAK PABRIK 456
9.1 Tata Letak Pabrik Overall 456
9.2 Tata Letak Alat Proses 457
BAB X ASPEK *SAFETY, HEALTH, AND ENVIRONMENT* (SHE) 463
10.1 Sistem Manajemen *Safety, Health, and Environment* 463
10.1.1 Konsep SHE 463
10.1.2 *Process Safety Management* (PSM) 466
10.1.3 *Environmental Management System* (EMS) 477
10.1.4 Struktur Organisasi SHE 485
10.2 Identifikasi Hazard Bahan 489
10.3 Identifikasi Hazard Proses dan Peralatan 505
10.4 Identifikasi Hazard Limbah 545
10.5 Identifikasi Hazard Paparan Kimia dan Fisis 558
10.6 Studi *Hazard and Operability* (HAZOP) 568
10.6.1 Pemilihan Peralatan 568
10.6.2 Studi HAZOP 570
10.6.3 Hasil Studi 604
10.7 Layer of Protection Analysis (LOPA) 605
10.7.1 Skenario Bahaya 605
10.7.2 Analisis Proteksi Berlapis 605
10.7.3 Metode Analisis 612
10.7.4 Matriks LOPA 616
10.8 *Dispersion Analysis* dan Klasifikasi Area Hazardous 623
10.8.1 Dispersion Analysis (Kebocoran Kritis) 623
10.8.2 Klasifikasi Area *Hazardous* 624

Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

BAB XI MANAJEMEN ORGANISASI PERUSAHAAN 629
11.1 Bentuk Perusahaan 629
11.2 Struktur Organisasi 630
11.3 Tugas dan Wewenang 630
11.4 Perhitungan Jam Kerja Karyawan 637
11.5 Perhitungan Jumlah Operator 639
11.6 Penggolongan Gaji Karyawan 640
11.7 Kesejahteraan Sosial 640
11.8 Manajemen Produksi 642
11.8.1 Perencanaan Produksi 642
11.8.2 Pengendalian Produksi 644
BAB XI ANALISIS EKONOMI 646
12.1 Perhitungan Indeks Harga 646
12.2 Modal Tetap (*Fixed Capital Investment*) 648
12.2.1 Perhitungan Harga Alat Proses dan Utilitas 648
12.2.2 Perhitungan Biaya *Raw Material, Supporting Materials*, dan *Sales* 667
12.2.3 Perhitungan Harga Tanah dan Bangunan 669
12.2.4 Perhitungan *Fixed Capital* 670
12.3 Biaya Produksi (*Manufacturing Cost*) 671
12.4 Modal Kerja (*Working Capital Investment*) 675
12.5 Pengeluaran Umum (*General Expenses*) 676
12.6 Analisis Keuntungan (*Profit*) 676
12.7 Analisis Kelayakan 677
12.7.1 Faktor Lang 677
12.7.2 *Return on Investment* (ROI) 677
12.7.3 *Payout Time* (POT) 678
12.7.4 *Discounted Cash Flow Rate of Return* (DCFRR) 679
12.7.5 *Break Even Point* (BEP) dan *Shutdown Point* (SDP) 681
12.8 Analisis Sensitivitas 683
BAB XIII KESIMPULAN 686
LAMPIRAN A (*DETAILED CALCULATION OF SELECTED EQUIPMENT*) 688
***ROTARY KILN* (RK-801)** 689
***ELECTROREFINNING CELL* (EC-601)** 709
***REVERBERATORY FURNACE* (RF-501)** 737
***DIGEST REACTOR* (R-801)** 766
LAMPIRAN B (*QUICK CALCULATION OF ALL EQUIPMENT*) 792

UNIVERSITAS
GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

CENTRIFUGE (CF-301) 793
CENTRIFUGE (CF-801) 794
CENTRIFUGE (FC-802) 798
CENTRIFUGE (CF-901) 799
CENTRIFUGE (CF-902) 800
CENTRIFUGE (CF-903) 801
FILTER PRESS (FP-701) 802
FILTER PRESS (FP-702) 806
ROTARY DRYER (RD-301) 807
ROTARY DRYER (RD-302) 821
ROTARY DRYER (RD-801) 825
ROTARY DRYER (RD-901) 826
ROTARY VACCUM FILTER (RV-801) 827
ROTARY VACCUM FILTER (RV-802) 835
TRAY DRYER (TD-701) 837
DIGEST REACTOR (R-801) 847
LEACHING REACTOR (R-701) 861
DILUTION REACTOR (R-802) 862
DILUTION REACTOR (R-803) 863
DILUTION REACTOR (R-806) 864
DILUTION REACTOR (R-903) 865
PRECIPITATION REACTOR (R-804) 866
PRECIPITATION REACTOR (R-807) 867
PRECIPITATION REACTOR (R-901) 868
PRECIPITATION REACTOR (R-904) 869
REVERBERATORY FURNACE (RF-501) 870
REVERBERATORY FURNACE (RF-502) 886
REVERBERATORY FURNACE (RF-701) 889
ROTARY KILN (RK-801) 891
ROTARY KILN (RK-901) 906
MIXER SETTLER (MS-801) 907
MIXER SETTLER (MS-802) 917
MIXER (MX-601) 918
MIXER (MX-701) 919
MIXER (MX-702) 920
MIXER (MX-703) 921
MIXER (MX-801) 922

UNIVERSITAS GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

MIXER (MX-802) 923
MIXER (MX-803) 924
CRYSTALLIZER (CR-601) 925
ELECTRIC KETTLE (EK-601) 934
ELECTRIC KETTLE (EK-602) 935
ELECTRIC KETTLE (EK-603) 946
ELECTRIC KETTLE (EK-604) 949
ELECTRIC KETTLE (EK-605) 951
ELECTROREFINNING CELL (EC-601) 952
ANODE CASTING (AC-601) 959
CATHODE CASTING (CC-601) 965
PRODUCT CASTING (PC-601) 966
PRODUCT CASTING (PC-602) 967
BALL MILL (BM-701) 968
BALL MILL (BM-801) 973
HAMMER CRUSHER (HC-501) 974
CIRCULAR VIBRATING SCREEN (CS-301) 977
GYRATORY SCREEN (GS-701) 983
ROTARY SCREEN (RS-101) 990
PRIMARY JIG (PJ-101) 996
PRIMARY JIG (PJ-102) 1006
PRIMARY JIG (PJ-103) 1007
PRIMARY JIG (PJ-201) 1008
PRIMARY JIG (PJ-202) 1009
PRIMARY JIG (PJ-301) 1010
PRIMARY JIG (PJ-302) 1011
PRIMARY JIG (PJ-303) 1012
PRIMARY JIG (PJ-304) 1013
SECONDARY JIG (SJ-101) 1014
SECONDARY JIG (SJ-102) 1015
SECONDARY JIG (SJ-103) 1016
SECONDARY JIG (SJ-104) 1017
SECONDARY JIG (SJ-105) 1018
SECONDARY JIG (SJ-201) 1019
SECONDARY JIG (SJ-202) 1027
SECONDARY JIG (SJ-203) 1028
AIR TABLE (AT-301) 1029

UNIVERSITAS
GADJAH MADA
**Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun**
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

DRY HIGH INTENSITY MAGNETIC SEPARATOR (DHIMS-401) 1036
HIGH TENSION ROLL SEPARATOR (HTRS-401) 1042
AIR COOLING PIT (AP-501) 1048
HOLDING POT (HP-601) 1051
SETTLING POND (SL-101) 1059
STORAGE BOX (SL-102) 1060
STORAGE BOX (SL-103) 1064
SETTLING POND (SL-201) 1065
SETTLING POND (SL-301) 1066
PRODUCT STORAGE (PS-801) 1067
PRODUCT STORAGE (PS-901) 1072
QUENCHING TANK (QT-701) 1073
STORAGE TANK (ST-501) 1079
STORAGE TANK (ST-502) 1080
STORAGE TANK (ST-601) 1081
STORAGE TANK (ST-603) 1082
STORAGE TANK (ST-604) 1083
STORAGE TANK (ST-605) 1089
STORAGE TANK (ST-701) 1090
STORAGE TANK (ST-702) 1091
STORAGE TANK (ST-801) 1092
STORAGE TANK (ST-802) 1097
STORAGE TANK (ST-803) 1098
STORAGE TANK (ST-804) 1099
STORAGE TANK (ST-805) 1100
STORAGE TANK (ST-806) 1101
STORAGE TANK (ST-901) 1102
STORAGE TANK (ST-902) 1103
LADLE (LL-501) 1104
LAUNDER (LD-501) 1110
LAUNDER (LD-502) 1116
LAUNDER (LD-503) 1117
BELT CONVEYOR (BC-101) 1118
BELT CONVEYOR (BC-102) 1122
BELT CONVEYOR (BC-103) 1123
BELT CONVEYOR (BC-104) 1124
BELT CONVEYOR (BC-301) 1125

UNIVERSITAS
GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

BELT CONVEYOR (BC-302) 1126
BELT CONVEYOR (BC-303) 1127
BELT CONVEYOR (BC-304) 1128
BELT CONVEYOR (BC-305) 1129
BELT CONVEYOR (BC-306) 1130
BELT CONVEYOR (BC-307) 1131
BELT CONVEYOR (BC-308) 1132
BELT CONVEYOR (BC-401) 1133
BELT CONVEYOR (BC-402) 1134
BELT CONVEYOR (BC-403) 1135
BELT CONVEYOR (BC-404) 1136
BELT CONVEYOR (BC-405) 1137
BELT CONVEYOR (BC-406) 1138
BELT CONVEYOR (BC-407) 1139
BELT CONVEYOR (BC-501) 1140
BELT CONVEYOR (BC-502) 1141
BELT CONVEYOR (BC-503) 1142
BELT CONVEYOR (BC-504) 1143
BELT CONVEYOR (BC-505) 1144
BELT CONVEYOR (BC-701) 1145
BELT CONVEYOR (BC-702) 1146
BELT CONVEYOR (BC-703) 1147
BELT CONVEYOR (BC-704) 1148
BELT CONVEYOR (BC-801) 1149
BELT CONVEYOR (BC-802) 1150
BELT CONVEYOR (BC-901) 1151
BELT CONVEYOR (BC-902) 1152
BUCKET ELEVATOR (BE-401) 1153
BUCKET ELEVATOR (BE-402) 1154
BUCKET ELEVATOR (BE-601) 1155
BUCKET ELEVATOR (BE-801) 1156
FLIGHT CONVEYOR (FC-801) 1160
FLIGHT CONVEYOR (FC-802) 1163
FLIGHT CONVEYOR (FC-901) 1164
FLIGHT CONVEYOR (FC-902) 1165
SCREW CONVEYOR (SC-301) 1166
SCREW CONVEYOR (SC-302) 1172

UNIVERSITAS
GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

SCREW CONVEYOR (SC-303) 1173
SCREW CONVEYOR (SC-304) 1174
SCREW CONVEYOR (SC-305) 1175
SCREW CONVEYOR (SC-601) 1176
SCREW CONVEYOR (SC-701) 1177
SCREW CONVEYOR (SC-702) 1178
SCREW CONVEYOR (SC-703) 1179
SCREW CONVEYOR (SC-801) 1180
SCREW CONVEYOR (SC-901) 1181
WATER PUMP (P-101) 1182
WATER PUMP (P-102) 1183
WATER PUMP (P-103) 1184
WATER PUMP (P-104) 1185
WATER PUMP (P-105) 1186
WATER PUMP (P-106) 1187
WATER PUMP (P-107) 1188
WATER PUMP (P-108) 1189
WATER PUMP (P-201) 1190
WATER PUMP (P-202) 1191
WATER PUMP (P-203) 1192
WATER PUMP (P-204) 1193
WATER PUMP (P-205) 1194
WATER PUMP (P-301) 1195
WATER PUMP (P-302) 1196
WATER PUMP (P-303) 1197
WATER PUMP (P-304) 1198
LIQUID PUMP (P-601) 1199
LIQUID PUMP (P-602) 1200
LIQUID PUMP (P-603) 1201
LIQUID PUMP (P-604) 1202
WATER PUMP (P-701) 1203
WATER PUMP (P-702) 1204
WATER PUMP (P-703) 1205
WATER PUMP (P-704) 1206
WATER PUMP (P-705) 1207
LIQUID PUMP (P-706) 1208
WATER PUMP (P-707) 1209

UNIVERSITAS
GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

LIQUID PUMP (P-708) 1210
LIQUID PUMP (P-801) 1211
LIQUID PUMP (P-802) 1212
LIQUID PUMP (P-803) 1213
LIQUID PUMP (P-804) 1214
LIQUID PUMP (P-805) 1215
LIQUID PUMP (P-806) 1216
LIQUID PUMP (P-807) 1217
LIQUID PUMP (P-808) 1218
LIQUID PUMP (P-809) 1219
LIQUID PUMP (P-810) 1220
LIQUID PUMP (P-811) 1221
LIQUID PUMP (P-812) 1222
LIQUID PUMP (P-813) 1223
LIQUID PUMP (P-814) 1224
LIQUID PUMP (P-815) 1225
LIQUID PUMP (P-816) 1226
SLURRY PUMP (SP-101) 1227
SLURRY PUMP (SP-102) 1233
SLURRY PUMP (SP-103) 1234
SLURRY PUMP (SP-104) 1235
SLURRY PUMP (SP-105) 1236
SLURRY PUMP (SP-106) 1237
SLURRY PUMP (SP-107) 1238
SLURRY PUMP (SP-108) 1239
SLURRY PUMP (SP-109) 1240
SLURRY PUMP (SP-110) 1241
SLURRY PUMP (SP-111) 1242
SLURRY PUMP (SP-112) 1243
SLURRY PUMP (SP-113) 1244
SLURRY PUMP (SP-114) 1245
SLURRY PUMP (SP-115) 1246
SLURRY PUMP (SP-201) 1247
SLURRY PUMP (SP-202) 1248
SLURRY PUMP (SP-203) 1249
SLURRY PUMP (SP-204) 1250
SLURRY PUMP (SP-205) 1251

UNIVERSITAS GADJAH MADA
Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

SLURRY PUMP (SP-206) 1252
SLURRY PUMP (SP-207) 1253
SLURRY PUMP (SP-208) 1254
SLURRY PUMP (SP-209) 1255
SLURRY PUMP (SP-210) 1256
SLURRY PUMP (SP-211) 1257
SLURRY PUMP (SP-212) 1258
SLURRY PUMP (SP-301) 1259
SLURRY PUMP (SP-302) 1260
SLURRY PUMP (SP-303) 1261
SLURRY PUMP (SP-304) 1262
SLURRY PUMP (SP-305) 1263
SLURRY PUMP (SP-701) 1264
SLURRY PUMP (SP-702) 1265
SLURRY PUMP (SP-703) 1266
SLURRY PUMP (SP-704) 1267
SLURRY PUMP (SP-705) 1268
SLURRY PUMP (SP-801) 1269
SLURRY PUMP (SP-802) 1270
SLURRY PUMP (SP-803) 1271
SLURRY PUMP (SP-804) 1272
SLURRY PUMP (SP-805) 1273
LAMPIRAN C (*CALCULATION OF UTILITY EQUIPMENT*) 1274
TANGKI PENYIMPANAN LARUTAN NaOCl (TU-1001) 1275
TANGKI PENYIMPANAN LARUTAN $NaHSO_3$ (TU-1002) 1282
TANGKI PENYIMPANAN ANTISCALANT (TU-1003) 1283
TANGKI PENYIMPANAN LARUTAN HCl (TU-1004) 1284
TANGKI PENYIMPANAN LARUTAN NaOH (TU-1005) 1285
TANGKI AIR DEMINERALISASI (TU-1006) 1286
MIXER LARUTAN HCl (MU-1001) 1287
MIXER LARUTAN NaOH (MU-1002) 1292
SCREENER (SU-1001) 1293
BASIN EKUALISASI (BU-1001) 1295
CLARIFIER (CL-1001) 1297
SAND FILTER (SF-1001) 1302
CARBON FILTER (CF-1001) 1304
SWRO (RO-1001) 1309

Prarancangan Pabrik Pemurnian Timah Aluvial Terintegrasi Recovery Rare Earth Element dan Thorium
dengan Bahan Baku 2.000.000 Ton/Tahun
Ibbnu 'Arobi Juang Darmajati, Prof. Himawan Tri Bayu Murti Petrus, S.T., M.E., D.Eng
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

BWRO (RO-1002) 1312
BASIN AIR DESALINASI (BU-1002) 1314
CATION EXCHANGER (IE-1001) 1316
ANION EXCHANGER (IE-1002) 1319
POMPA UTILITAS (PU-1006) 1322
COOLING TOWER (CT-1001) 1329
DEAERATOR (DE-1001) 1337
BOILER (B-1001) 1338
DAFTAR PUSTAKA 1339