**Surrogate-model-based, Particle Swarm Optimization and Genetic Algorithm Techniques applied to the Multi-objective Operational Problem of the Fluid Catalytic Cracking Process**

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**Supplementary Material – S1: The GA parameters tuning procedure**

Initially, 32 tests were run to evaluate *FG*, *LPG*, *GLN*, *LCO* and *CO* in surrogate models to identify the most relevant parameters that maximize *GLN* (assay 22 in Table S1-1). The significant GA parameters were identified based on a fractional factorial design. Subsequently, each parameter was evaluated by an exhaustion method (keeping the other ones according to the values proposed by Carroll (1999)), checking the whole range under consideration, providing the highest values for *GLN* (Tables S1-2 to S1-6).

**GA parameters**:

Population size (popz): between 5-100

Number of generation (Gen): between 26-200

Creep mutation (Mutarras): between 0.02-0.04

Jump mutation (MutUni): between 0.01-0.02

Uniform crossover (CruzUni): 0.5-0.7

***Table S1-1*** Assays to select the initial set of parameters of GA technique

|  |  |  |  |
| --- | --- | --- | --- |
| Run | **GA parameters** | **FCCU critical variables** | **Responses using surrogate models** |
| Popz | CruzUni | Mutarras | MutUni | Gen | *RA1* (m3/s) | *RA2* (m3/s) | *TR2*(K) | *TALIM* (K) | *TRX* (K) | *FG* (kg/s) | *LPG* (kg/s) | *GLN* (kg/s) | *LCO* (kg/s) | *CO* (kg/s) |
| 1 | 5 | 0.5 | 0.02 | 0.01 | 26 | 2.75 | 0.280 | 892.7 | 368.7 | 801.7 | 3.615 | 10.561 | 36.425 | 6.014 | 7.174 |
| 2 | 100 | 0.5 | 0.02 | 0.01 | 26 | 2.77 | 0.280 | 893.2 | 369.3 | 795.3 | 2.950 | 10.934 | 36.892 | 6.825 | 9.451 |
| 3 | 5 | 0.7 | 0.02 | 0.01 | 26 | 2.77 | 0.280 | 893.2 | 369.9 | 791.4 | 2.725 | 11.284 | 37.032 | 7.074 | 10.649 |
| 4 | 100 | 0.7 | 0.02 | 0.01 | 26 | 2.78 | 0.280 | 892.8 | 368.7 | 800.4 | 3.536 | 9.921 | 36.572 | 6.222 | 7.650 |
| 5 | 5 | 0.5 | 0.04 | 0.01 | 26 | 2.65 | 0.280 | 893.6 | 371.7 | 803.9 | 4.026 | 13.043 | 36.603 | 5.348 | 6.120 |
| 6 | 100 | 0.5 | 0.04 | 0.01 | 26 | 2.78 | 0.280 | 893.8 | 369.0 | 791.7 | 2.782 | 10.473 | 37.090 | 7.126 | 10.907 |
| 7 | 5 | 0.7 | 0.04 | 0.01 | 26 | 2.75 | 0.280 | 893.5 | 370.0 | 801.2 | 3.469 | 11.578 | 36.458 | 6.153 | 7.455 |
| 8 | 100 | 0.7 | 0.04 | 0.01 | 26 | 2.76 | 0.280 | 893.8 | 369.1 | 793.3 | 2.783 | 11.001 | 36.861 | 7.039 | 10.363 |
| 9 | 5 | 0.5 | 0.02 | 0.02 | 26 | 2.75 | 0.280 | 893.2 | 370.5 | 797.4 | 3.053 | 12.012 | 36.688 | 6.556 | 8.551 |
| 10 | 100 | 0.5 | 0.02 | 0.02 | 26 | 2.77 | 0.280 | 892.7 | 369.0 | 790.3 | 2.782 | 10.384 | 37.049 | 7.188 | 11.191 |
| 11 | 5 | 0.7 | 0.02 | 0.02 | 26 | 2.77 | 0.280 | 897.9 | 370.1 | 792.1 | 2.479 | 11.920 | 36.824 | 7.200 | 11.610 |
| 12 | 100 | 0.7 | 0.02 | 0.02 | 26 | 2.78 | 0.280 | 893.7 | 368.0 | 793.9 | 2.956 | 9.676 | 36.975 | 6.991 | 10.327 |
| 13 | 5 | 0.5 | 0.04 | 0.02 | 26 | 2.66 | 0.280 | 893.8 | 371.8 | 805.3 | 4.241 | 12.937 | 36.541 | 5.172 | 5.700 |
| 14 | 100 | 0.5 | 0.04 | 0.02 | 26 | 2.78 | 0.280 | 895.4 | 370.0 | 790.3 | 2.578 | 11.397 | 37.063 | 7.171 | 11.571 |
| 15 | 5 | 0.7 | 0.04 | 0.02 | 26 | 2.77 | 0.280 | 894.8 | 370.5 | 795.9 | 2.839 | 11.898 | 36.781 | 6.792 | 9.561 |
| 16 | 100 | 0.7 | 0.04 | 0.02 | 26 | 2.64 | 0.280 | 892.7 | 372.4 | 805.4 | 4.470 | 12.987 | 36.708 | 4.849 | 5.153 |
| 17 | 5 | 0.5 | 0.02 | 0.01 | 200 | 2.78 | 0.280 | 892.7 | 367.9 | 793.7 | 3.012 | 9.371 | 37.009 | 6.960 | 10.178 |
| 18 | 100 | 0.5 | 0.02 | 0.01 | 200 | 2.77 | 0.280 | 893.4 | 367.8 | 795.8 | 3.062 | 9.735 | 36.804 | 6.811 | 9.639 |
| 19 | 5 | 0.7 | 0.02 | 0.01 | 200 | 2.78 | 0.280 | 892.7 | 367.7 | 795.6 | 3.134 | 9.270 | 36.910 | 6.781 | 9.511 |
| 20 | 100 | 0.7 | 0.02 | 0.01 | 200 | 2.78 | 0.280 | 892.8 | 368.3 | 794.8 | 3.033 | 9.832 | 36.980 | 6.866 | 9.699 |
| 21 | 5 | 0.5 | 0.04 | 0.01 | 200 | 2.64 | 0.280 | 892.7 | 372.6 | 805.3 | 4.471 | 13.006 | 36.713 | 4.852 | 5.161 |
| **22** | **100** | **0.5** | **0.04** | **0.01** | **200** | **2.78** | **0.280** | **892.7** | **369.0** | **792.0** | **2.854** | **10.366** | **37.120** | **7.062** | **10.513** |
| 23 | 5 | 0.7 | 0.04 | 0.01 | 200 | 2.78 | 0.280 | 892.7 | 368.0 | 792.2 | 2.940 | 9.382 | 37.070 | 7.084 | 10.740 |
| 24 | 100 | 0.7 | 0.04 | 0.01 | 200 | 2.78 | 0.280 | 892.9 | 368.5 | 793.1 | 2.926 | 9.946 | 37.061 | 7.013 | 10.304 |
| 25 | 5 | 0.5 | 0.02 | 0.02 | 200 | 2.78 | 0.280 | 892.7 | 367.8 | 792.7 | 2.971 | 9.251 | 37.043 | 7.048 | 10.601 |
| 26 | 100 | 0.5 | 0.02 | 0.02 | 200 | 2.77 | 0.280 | 893.1 | 368.3 | 792.9 | 2.881 | 10.051 | 36.951 | 7.053 | 10.502 |
| 27 | 5 | 0.7 | 0.02 | 0.02 | 200 | 2.77 | 0.280 | 892.8 | 368.0 | 796.0 | 3.105 | 9.733 | 36.822 | 6.753 | 9.368 |
| 28 | 100 | 0.7 | 0.02 | 0.02 | 200 | 2.77 | 0.280 | 892.7 | 368.7 | 791.7 | 2.837 | 10.190 | 37.012 | 7.117 | 10.778 |
| 29 | 5 | 0.5 | 0.04 | 0.02 | 200 | 2.64 | 0.280 | 892.7 | 372.3 | 805.6 | 4.491 | 12.967 | 36.705 | 4.826 | 5.112 |
| 30 | 100 | 0.5 | 0.04 | 0.02 | 200 | 2.77 | 0.280 | 892.7 | 368.7 | 793.5 | 2.905 | 10.337 | 36.968 | 6.980 | 10.102 |
| 31 | 5 | 0.7 | 0.04 | 0.02 | 200 | 2.78 | 0.280 | 892.7 | 367.7 | 793.7 | 3.024 | 9.228 | 36.999 | 6.959 | 10.217 |
| 32 | 100 | 0.7 | 0.04 | 0.02 | 200 | 2.78 | 0.280 | 892.9 | 367.7 | 795.6 | 3.126 | 9.306 | 36.906 | 6.788 | 9.545 |

***Table S1-2*** Assays to select the best number of generations (Gen) getting the highest *GLN* (in bold). Popz, CruzUni, Mutarras and MutUni parameters were fixed as run the 22 in *Table S1-1*

|  |  |  |  |
| --- | --- | --- | --- |
| Run | **GA parameters** | **FCCU critical variables** | **Responses** |
| Popz | CruzUni | Mutarras | MutUni | Gen | *RA1* (m3/s) | *RA2* (m3/s) | *TR2*(K) | *TALIM* (K) | *TRX* (K) | *FG* (kg/s) | *LPG* (kg/s) | *GLN* (kg/s) | *LCO* (kg/s) | *CO* (kg/s) |
| 33 | 100 | 0.5 | 0.04 | 0.01 | 26 | 2.78 | 0.280 | 893.8 | 369.0 | 791.7 | 2.782 | 10.473 | 37.090 | 7.126 | 10.907 |
| 34 | 100 | 0.5 | 0.04 | 0.01 | 36 | 2.78 | 0.280 | 893.8 | 369.0 | 791.7 | 2.782 | 10.473 | 37.090 | 7.126 | 10.907 |
| 35 | 100 | 0.5 | 0.04 | 0.01 | 46 | 2.78 | 0.280 | 893.8 | 369.0 | 791.7 | 2.782 | 10.473 | 37.090 | 7.126 | 10.907 |
| 36 | 100 | 0.5 | 0.04 | 0.01 | 56 | 2.78 | 0.280 | 893.8 | 369.0 | 791.7 | 2.782 | 10.473 | 37.090 | 7.126 | 10.907 |
| 37 | 100 | 0.5 | 0.04 | 0.01 | 66 | 2.78 | 0.280 | 893.8 | 369.0 | 791.7 | 2.782 | 10.473 | 37.090 | 7.126 | 10.907 |
| 38 | 100 | 0.5 | 0.04 | 0.01 | 76 | 2.78 | 0.280 | 893.8 | 369.0 | 791.7 | 2.782 | 10.473 | 37.090 | 7.126 | 10.907 |
| 39 | 100 | 0.5 | 0.04 | 0.01 | 86 | 2.78 | 0.280 | 893.8 | 369.0 | 791.7 | 2.782 | 10.473 | 37.090 | 7.126 | 10.907 |
| 40 | 100 | 0.5 | 0.04 | 0.01 | 96 | 2.78 | 0.280 | 893.8 | 369.0 | 791.7 | 2.782 | 10.473 | 37.090 | 7.126 | 10.907 |
| 41 | 100 | 0.5 | 0.04 | 0.01 | 106 | 2.78 | 0.280 | 893.2 | 369.3 | 791.3 | 2.785 | 10.612 | 37.130 | 7.111 | 10.828 |
| 42 | 100 | 0.5 | 0.04 | 0.01 | 116 | 2.78 | 0.280 | 893.2 | 369.3 | 791.3 | 2.785 | 10.612 | 37.130 | 7.111 | 10.828 |
| 43 | 100 | 0.5 | 0.04 | 0.01 | 126 | 2.78 | 0.280 | 893.2 | 369.3 | 791.3 | 2.785 | 10.612 | 37.130 | 7.111 | 10.828 |
| 44 | 100 | 0.5 | 0.04 | 0.01 | 136 | 2.78 | 0.280 | 893.2 | 369.3 | 791.3 | 2.785 | 10.612 | 37.130 | 7.111 | 10.828 |
| 45 | 100 | 0.5 | 0.04 | 0.01 | 146 | 2.78 | 0.280 | 893.2 | 369.3 | 791.3 | 2.785 | 10.612 | 37.130 | 7.111 | 10.828 |
| 46 | 100 | 0.5 | 0.04 | 0.01 | 156 | 2.78 | 0.280 | 893.2 | 369.3 | 791.3 | 2.785 | 10.612 | 37.130 | 7.111 | 10.828 |
| **47** | **100** | **0.5** | **0.04** | **0.01** | **166** | **2.78** | **0.280** | **892.7** | **369.0** | **792.0** | **2.854** | **10.366** | **37.120** | **7.062** | **10.513** |
| 48 | 100 | 0.5 | 0.04 | 0.01 | 176 | 2.78 | 0.280 | 892.7 | 369.0 | 792.0 | 2.854 | 10.366 | 37.120 | 7.062 | 10.513 |
| 49 | 100 | 0.5 | 0.04 | 0.01 | 186 | 2.78 | 0.280 | 892.7 | 369.0 | 792.0 | 2.854 | 10.366 | 37.120 | 7.062 | 10.513 |
| 50 | 100 | 0.5 | 0.04 | 0.01 | 196 | 2.78 | 0.280 | 892.7 | 369.0 | 792.0 | 2.854 | 10.366 | 37.120 | 7.062 | 10.513 |
| 51 | 100 | 0.5 | 0.04 | 0.01 | 200 | 2.78 | 0.280 | 892.7 | 369.0 | 792.0 | 2.854 | 10.366 | 37.120 | 7.062 | 10.513 |

***Table S1-3*** Assays to select the best Population size (Popz) getting the highest *GLN* (in bold). CruzUni, Mutarras and MutUni parameters were fixed as run the 22 in *Table S1-1*. Gen parameter was fixed at 166 (run 47 in *Table S1-2*)

|  |  |  |  |
| --- | --- | --- | --- |
| Run | **GA parameters** | **FCCU critical variables** | **Responses** |
| Popz | CruzUni | Mutarras | MutUni | Gen | *RA1* (m3/s) | *RA2* (m3/s) | *TR2*(K) | *TALIM* (K) | *TRX* (K) | *FG* (kg/s) | *LPG* (kg/s) | *GLN* (kg/s) | *LCO* (kg/s) | *CO* (kg/s) |
| 52 | 5 | 0.5 | 0.04 | 0.01 | 166 | 2.64 | 0.280 | 892.7 | 372.6 | 805.3 | 4.456 | 13.012 | 36.714 | 4.866 | 5.188 |
| 53 | 15 | 0.5 | 0.04 | 0.01 | 166 | 2.78 | 0.280 | 892.9 | 369.0 | 793.0 | 2.885 | 10.419 | 37.077 | 6.999 | 10.205 |
| 54 | 25 | 0.5 | 0.04 | 0.01 | 166 | 2.77 | 0.280 | 892.8 | 368.8 | 792.9 | 2.869 | 10.392 | 36.986 | 7.026 | 10.308 |
| 55 | 35 | 0.5 | 0.04 | 0.01 | 166 | 2.77 | 0.280 | 892.8 | 367.8 | 795.4 | 3.076 | 9.582 | 36.837 | 6.809 | 9.618 |
| 56 | 45 | 0.5 | 0.04 | 0.01 | 166 | 2.78 | 0.280 | 892.7 | 368.3 | 792.2 | 2.919 | 9.673 | 37.085 | 7.074 | 10.628 |
| 57 | 55 | 0.5 | 0.04 | 0.01 | 166 | 2.77 | 0.280 | 893.8 | 371.1 | 789.6 | 2.578 | 12.163 | 37.010 | 7.033 | 11.107 |
| 58 | 65 | 0.5 | 0.04 | 0.01 | 166 | 2.77 | 0.280 | 892.8 | 369.0 | 789.4 | 2.761 | 10.394 | 37.057 | 7.233 | 11.511 |
| 59 | 75 | 0.5 | 0.04 | 0.01 | 166 | 2.78 | 0.280 | 893.4 | 368.2 | 792.0 | 2.876 | 9.740 | 37.064 | 7.118 | 10.891 |
| 60 | 85 | 0.5 | 0.04 | 0.01 | 166 | 2.77 | 0.280 | 892.8 | 368.3 | 792.9 | 2.900 | 9.986 | 36.962 | 7.039 | 10.430 |
| 61 | 95 | 0.5 | 0.04 | 0.01 | 166 | 2.78 | 0.280 | 893.2 | 367.8 | 792.1 | 2.925 | 9.328 | 37.044 | 7.109 | 10.916 |
| **62** | **100** | **0.5** | **0.04** | **0.01** | **166** | **2.78** | **0.280** | **892.7** | **369.0** | **792.0** | **2.854** | **10.366** | **37.120** | **7.062** | **10.513** |

***Table S1-4*** Assays to select the best Uniform crossover (CruzUni) getting the highest *GLN* (in bold). Mutarras and MutUni parameters were fixed as run the 22 in *Table S1-1*. Gen and Popz parameters were fixed at 166 (run 47 in *Table S1-2*) and 100 (run 62 in *Table S1-3*), respectively

|  |  |  |  |
| --- | --- | --- | --- |
| Run | **GA parameters** | **FCCU critical variables** | **Responses** |
| Popz | CruzUni | Mutarras | MutUni | Gen | *RA1* (m3/s) | *RA2* (m3/s) | *TR2*(K) | *TALIM* (K) | *TRX* (K) | *FG* (kg/s) | *LPG* (kg/s) | *GLN* (kg/s) | *LCO* (kg/s) | *CO* (kg/s) |
| **63** | **100** | **0.5** | **0.04** | **0.01** | **166** | **2.78** | **0.280** | **892.7** | **369.0** | **792.0** | **2.854** | **10.366** | **37.120** | **7.062** | **10.513** |
| 64 | 100 | 0.6 | 0.04 | 0.01 | 166 | 2.78 | 0.280 | 892.7 | 368.2 | 793.6 | 2.980 | 9.656 | 37.033 | 6.972 | 10.164 |
| 65 | 100 | 0.7 | 0.04 | 0.01 | 166 | 2.78 | 0.280 | 892.9 | 368.5 | 793.1 | 2.926 | 9.946 | 37.061 | 7.013 | 10.304 |

***Table S1-5*** Assays to select the best Jump mutation (MutUni) getting the highest *GLN* (in bold). Mutarras parameter was fixed as run the 22 in *Table S1-1*. Gen, Popz and CruzUni parameters were fixed at 166 (run 47 in *Table S1-2*), 100 (run 62 in *Table S1-3*) and 0.04 (run 63 in *Table S1-4*), respectively

|  |  |  |  |
| --- | --- | --- | --- |
| Run | **GA parameters** | **FCCU critical variables** | **Responses** |
| Pop | CruzUni | Mutarras | MutUni | Gen | *RA1* (m3/s) | *RA2* (m3/s) | *TR2*(K) | *TALIM* (K) | *TRX* (K) | *FG* (kg/s) | *LPG* (kg/s) | *GLN* (kg/s) | *LCO* (kg/s) | *CO* (kg/s) |
| **66** | **100** | **0.5** | **0.04** | **0.01** | **166** | **2.78** | **0.280** | **892.7** | **369.0** | **792.0** | **2.854** | **10.366** | **37.120** | **7.062** | **10.513** |
| 67 | 100 | 0.5 | 0.04 | 0.02 | 166 | 2.77 | 0.280 | 892.7 | 368.8 | 793.8 | 2.918 | 10.406 | 36.959 | 6.950 | 9.966 |

***Table S1-6*** Assays to select the best Creep mutation (Mutarras) getting the highest *GLN* (in bold). Gen, Popz, CruzUni and MutUni parameters were fixed at 166 (run 47 in *Table S1-2*), 100 (run 62 in *Table S1-3*), 0.04 (run 63 in *Table S1-4*) and 0.01 (run 66 in *Table S1-5*, respectively

|  |  |  |  |
| --- | --- | --- | --- |
| Run | **GA parameters** | **FCCU critical variables** | **Responses** |
| Popz | CruzUni | Mutarras | MutUni | Gen | *RA1* (m3/s) | *RA2* (m3/s) | *TR2*(K) | *TALIM* (K) | *TRX* (K) | *FG* (kg/s) | *LPG* (kg/s) | *GLN* (kg/s) | *LCO* (kg/s) | *CO* (kg/s) |
| 68 | 100 | 0.5 | 0.02 | 0.01 | 166 | 2.77 | 0.280 | 893.4 | 367.8 | 795.8 | 3.062 | 9.735 | 36.804 | 6.811 | 9.639 |
| 69 | 100 | 0.5 | 0.025 | 0.01 | 166 | 2.78 | 0.280 | 892.9 | 368.0 | 795.0 | 3.071 | 9.509 | 36.949 | 6.847 | 9.707 |
| 70 | 100 | 0.5 | 0.03 | 0.01 | 166 | 2.78 | 0.280 | 893.4 | 367.8 | 795.0 | 3.051 | 9.491 | 36.924 | 6.874 | 9.867 |
| 71 | 100 | 0.5 | 0.035 | 0.01 | 166 | 2.77 | 0.280 | 892.8 | 369.0 | 794.0 | 2.909 | 10.615 | 36.958 | 6.932 | 9.873 |
| **72** | **100** | **0.5** | **0.04** | **0.01** | **166** | **2.78** | **0.280** | **892.7** | **369.0** | **792.0** | **2.854** | **10.366** | **37.120** | **7.062** | **10.513** |