

APPENDICES

Appendix A: Variable input data for simulation

(a) Engine revolution in rpm	= 1500, 2000, 2500, 3000, 4000
(b) No of stroke	= 4.0
Total angle of rotation in degree	= 720.0
(c) Cylinder specifications:	
- Compression ratio	= 15, 16, 17, 18
- Cylinder diameter	= 0.110 m
- Cylinder bore	= 0.0870 m
- Length of connecting rod	= 0.230 m
(e) EVO: Angle at which exhaust valve opens	= 144.5 bTDC
EVC: Angle at which exhaust valve closed	= 364.5 aTDC
IVO: Angle at which inlet valve open	= 355.5 bTDC
IVC: Angle at which inlet valve closed (IVC)	= 575.5 aTDC
ACSB: Angle at which compression stroke begin	= 575.5 CAD aTDC
AIJ: Angle of injection (AIJ)	= 697.0 bTDC
(f) Trapped pressure for cylinder	= 1.0 bar
Trapped temperature for cylinder	= 300.0 K

(g) Annand's coefficient for heat transfer	= 0.26, 0.7
(h) Inlet valve diameter/bore	= 0.4410
Exhaust valve diameter/bore	= 0.3990
Cylinder head wall temperature	= 500 K
Piston wall temperature	= 500 K
Inlet valve temperature	= 500 K
Exhaust valve temperature	= 500 K
Surface temperature for loner top	= 500 K
Surface temperature for loner bottom	= 410 K

(i) Fuel Properties:-

Carbon atom in fuel (C)	= 16.0, for biodiesel
	= 12.0, for diesel
Hydrogen atom in fuel (H)	= 32.0, for biodiesel
	= 23.0, for diesel
Oxygen atom in fuel (O)	= 2.0, for biodiesel
	= 0.0, for diesel
Calorific value of fuel (CV)	= 34587.0 kJ/kg, for biodiesel
	= 42000.0 kJ/kg, for diesel
Fuels vapour viscosity parameters	= 9.88×10^{-4} kg/m.sec (for biodiesel)

(j) Internal energy coefficients for biodiesel and diesel = -1.11320×10^5
= -8.352×10^3
= 5.16538×10^{-1}
= -2.0042×10^{-4}
= 3.38×10^{-8}

(k) Equivalence ratio = 0.58

Fraction residuals = 0.03

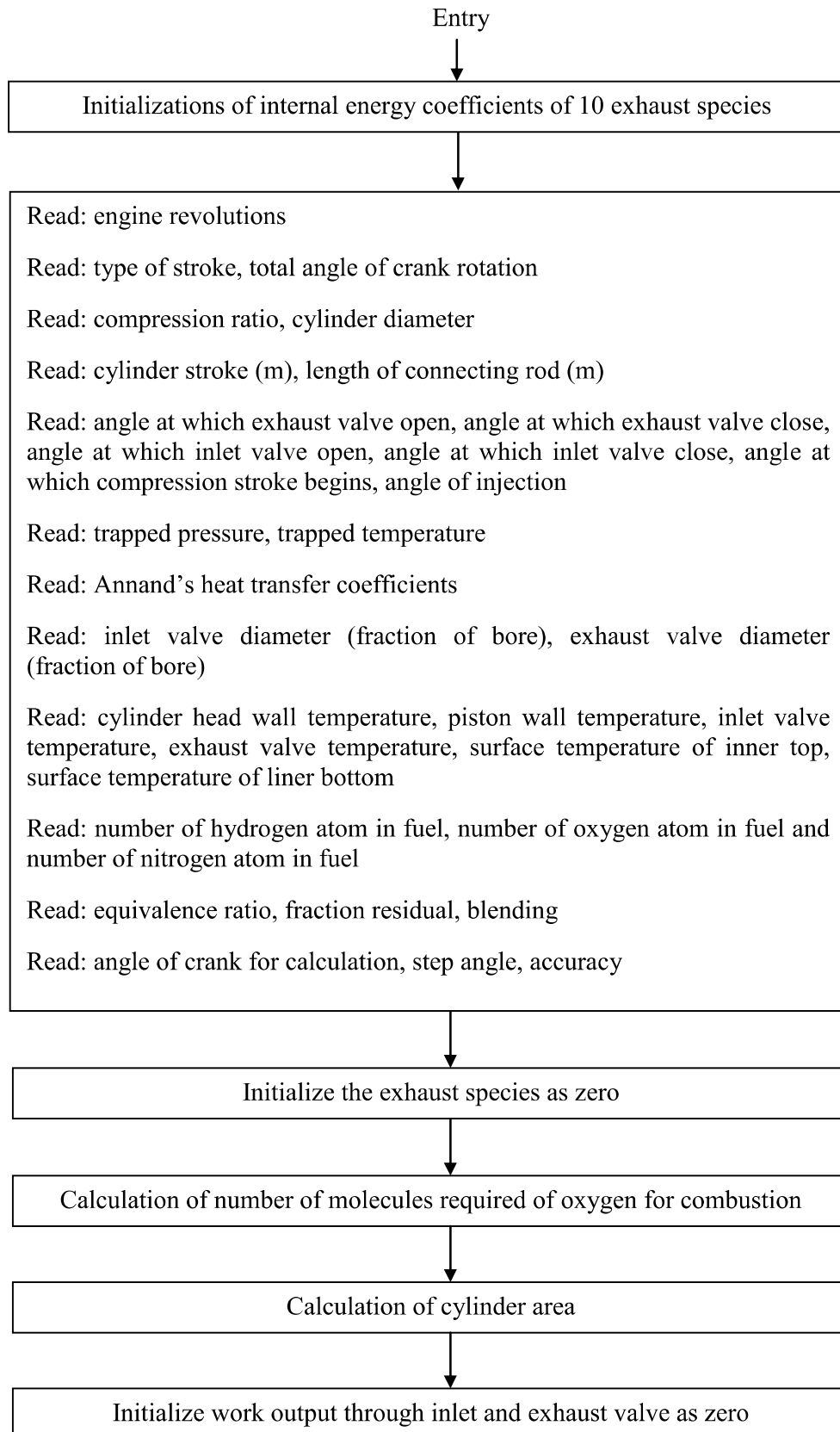
Multiplication factor for rated CO = 0.50

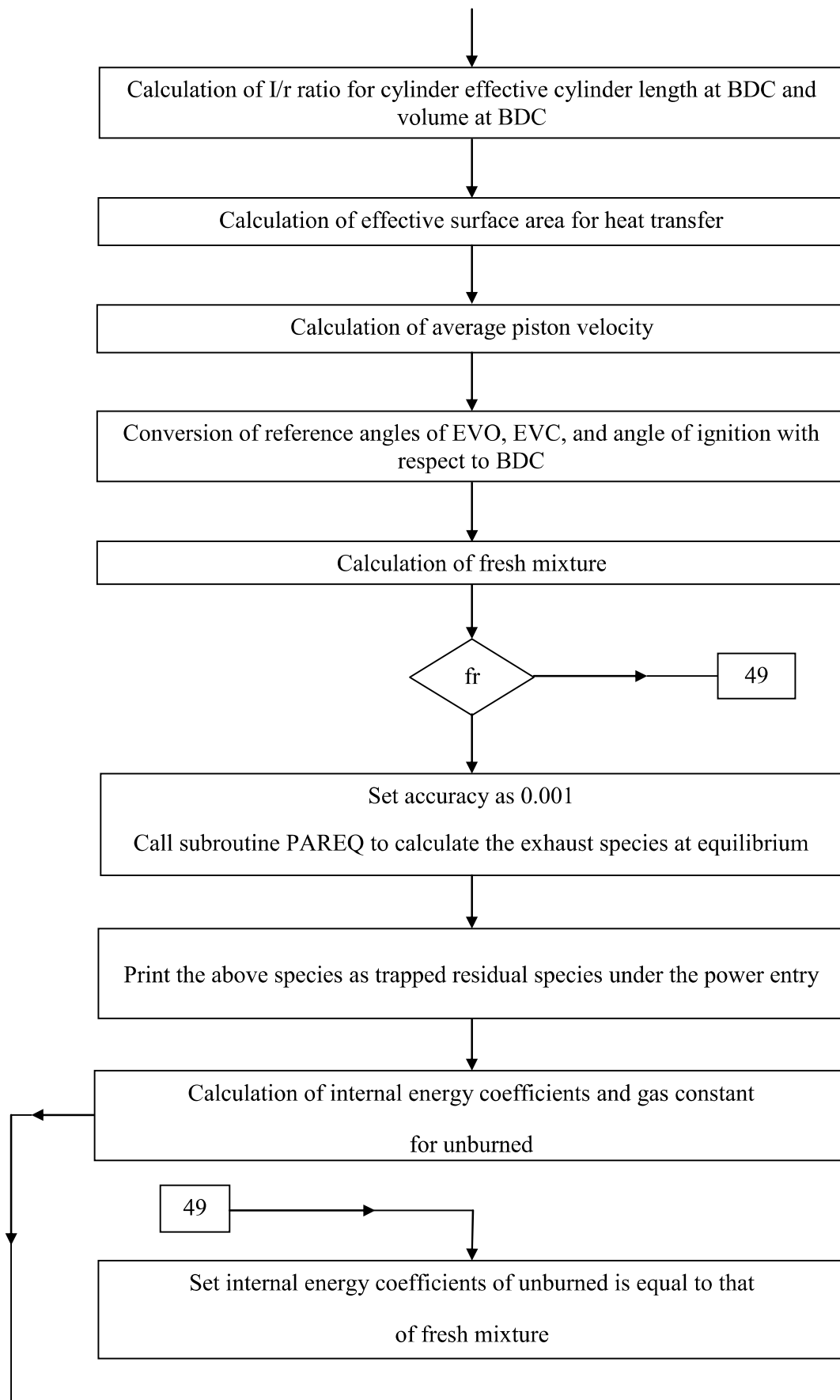
(l) Step angle in degree = 0.50

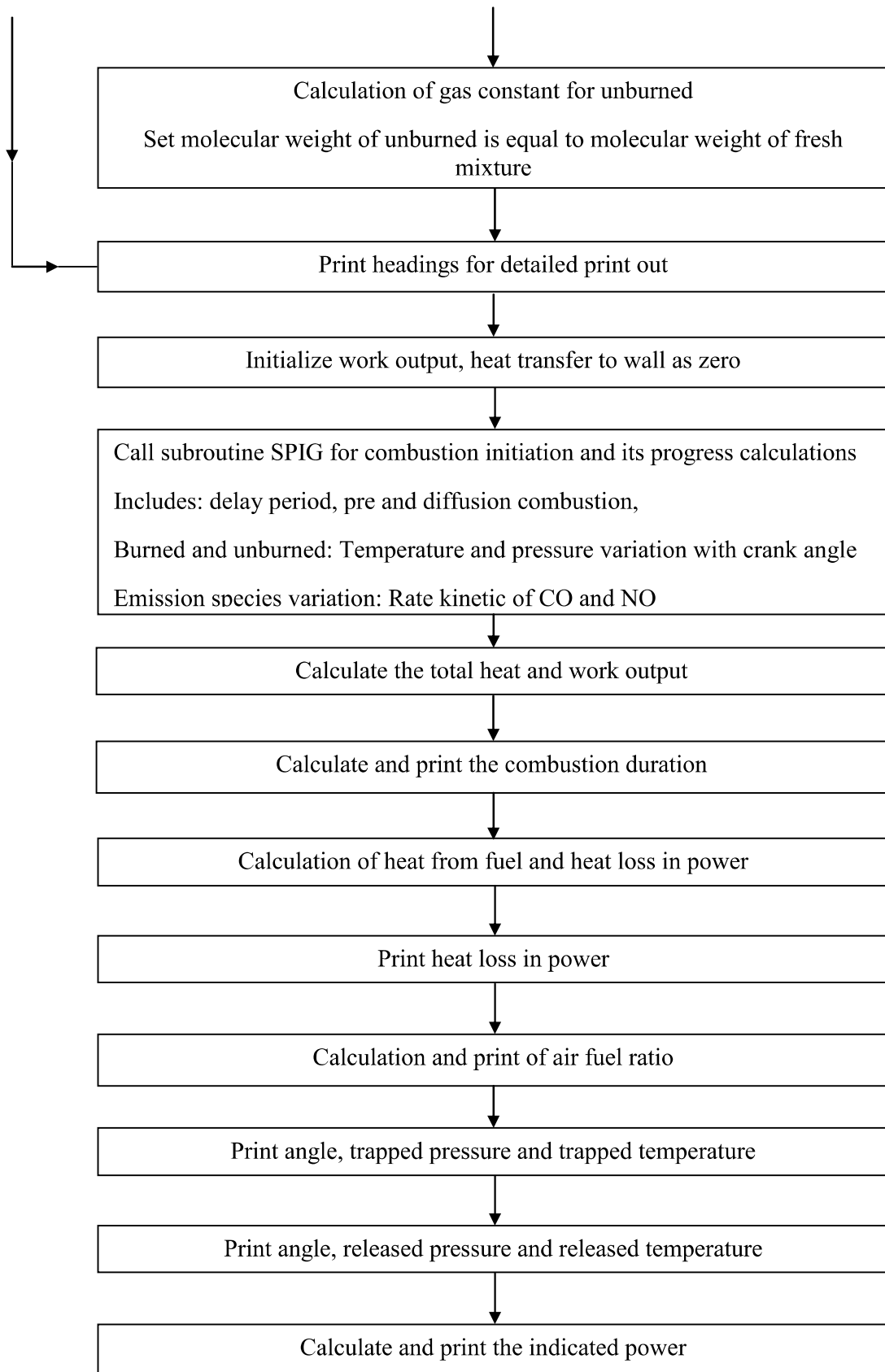
Angle of crank for calculation in degree = 3600.0 (10 revolutions)

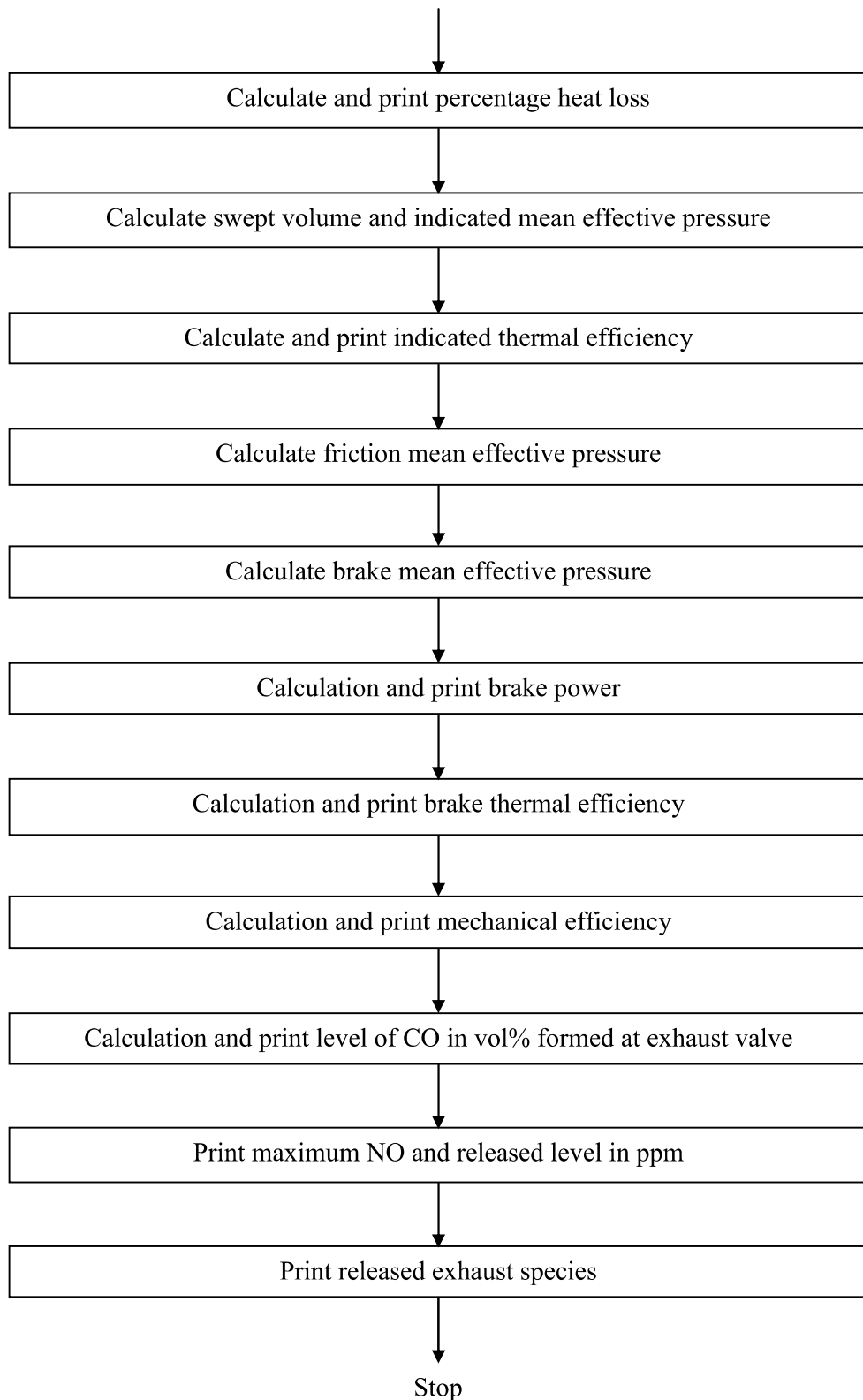
Accuracy = 0.001

Appendix B: Flow chart of main programme









Appendix C: SUBROUTINES

C.1: Flow chart for SUBROUTINE DIFOR: This subroutine is used for differentiating of the dependent variable in the cylinder. HRK (I) is the rate of change of variables with respect to crank angle, where, I = 1 for cylinder pressure (N/m²)

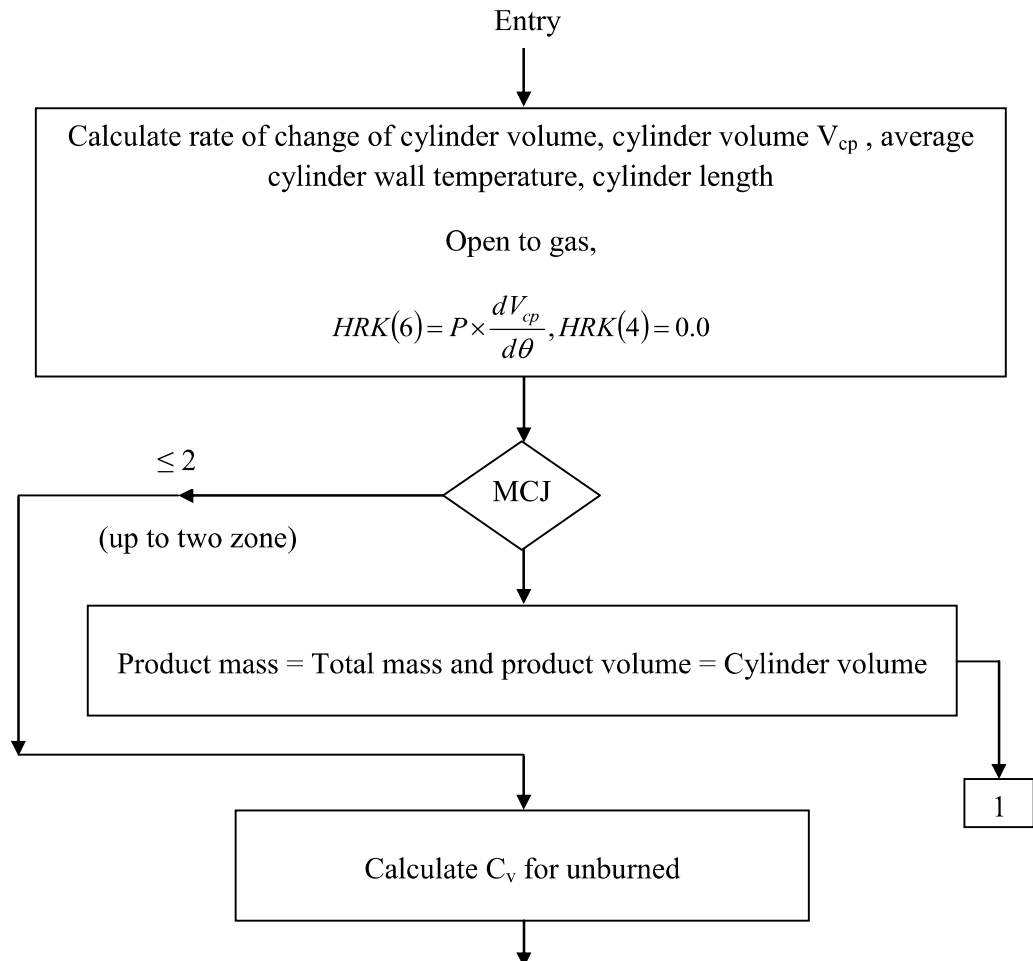
I = 2 for unburned temperature (K)

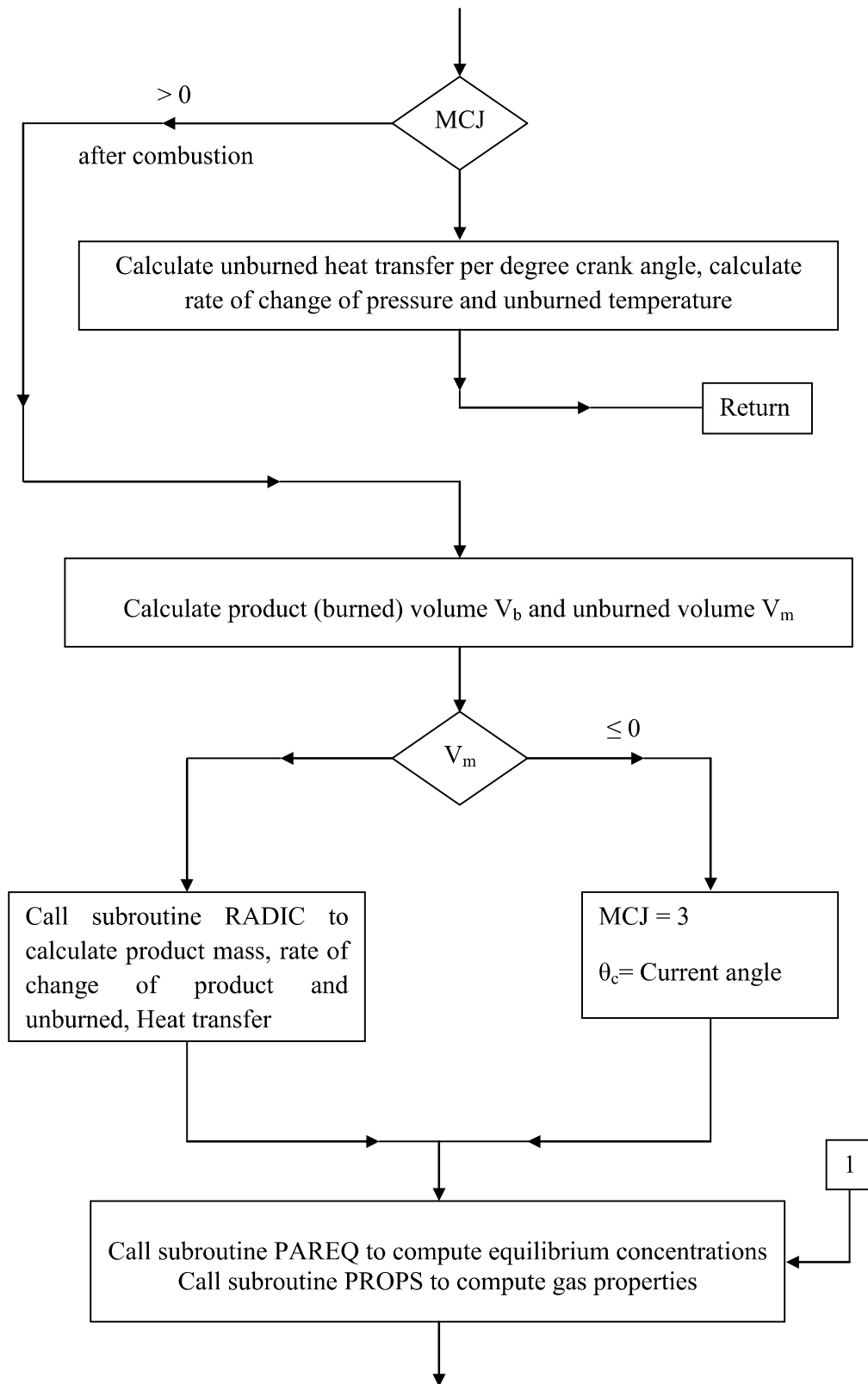
I = 3 for burned temperature (K)

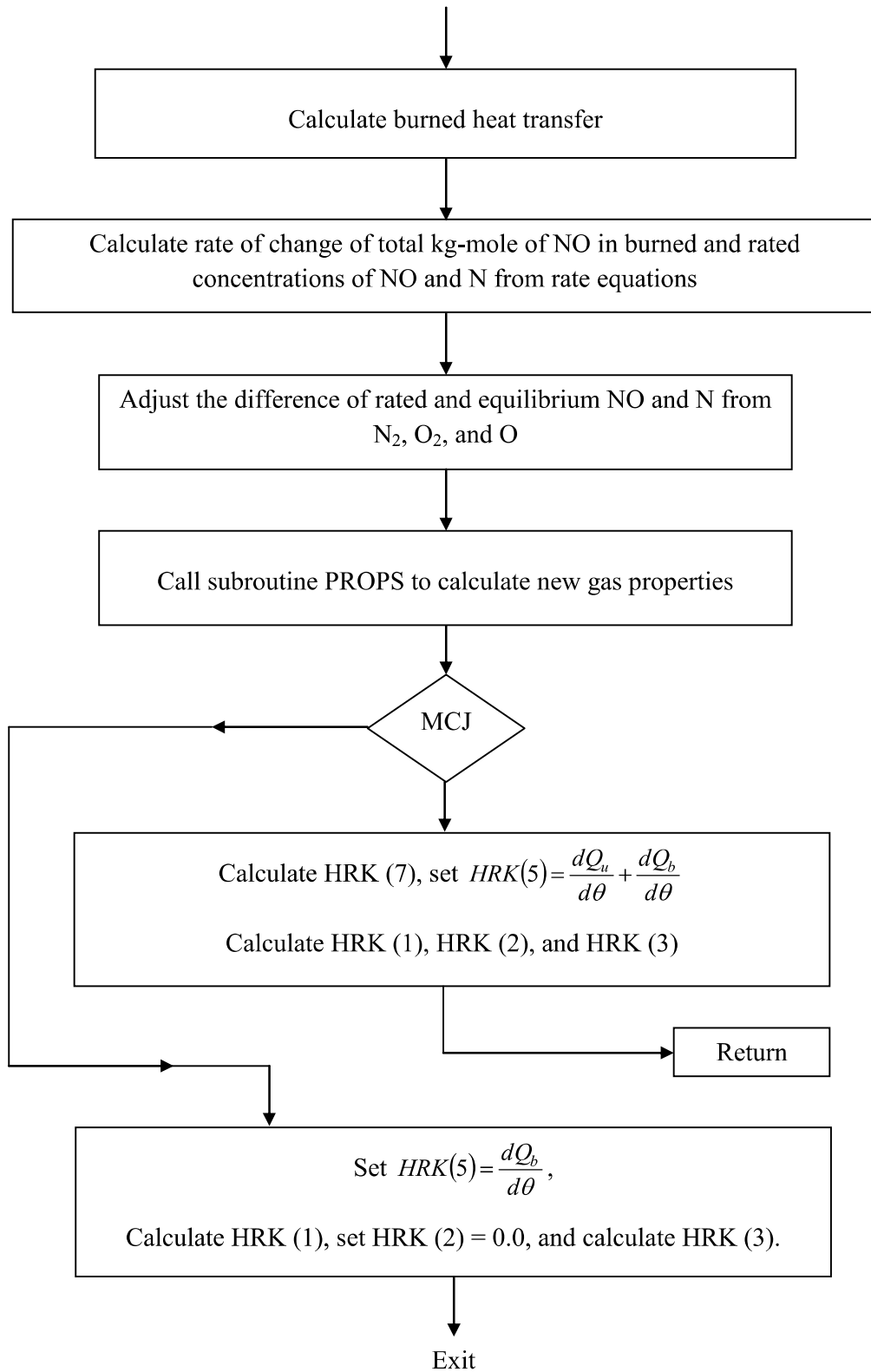
I = 4 for total unburned mass (kg)

I = 5 for total heat transfer to wall (J)

I = 6 for total kg-mol of NO in burned

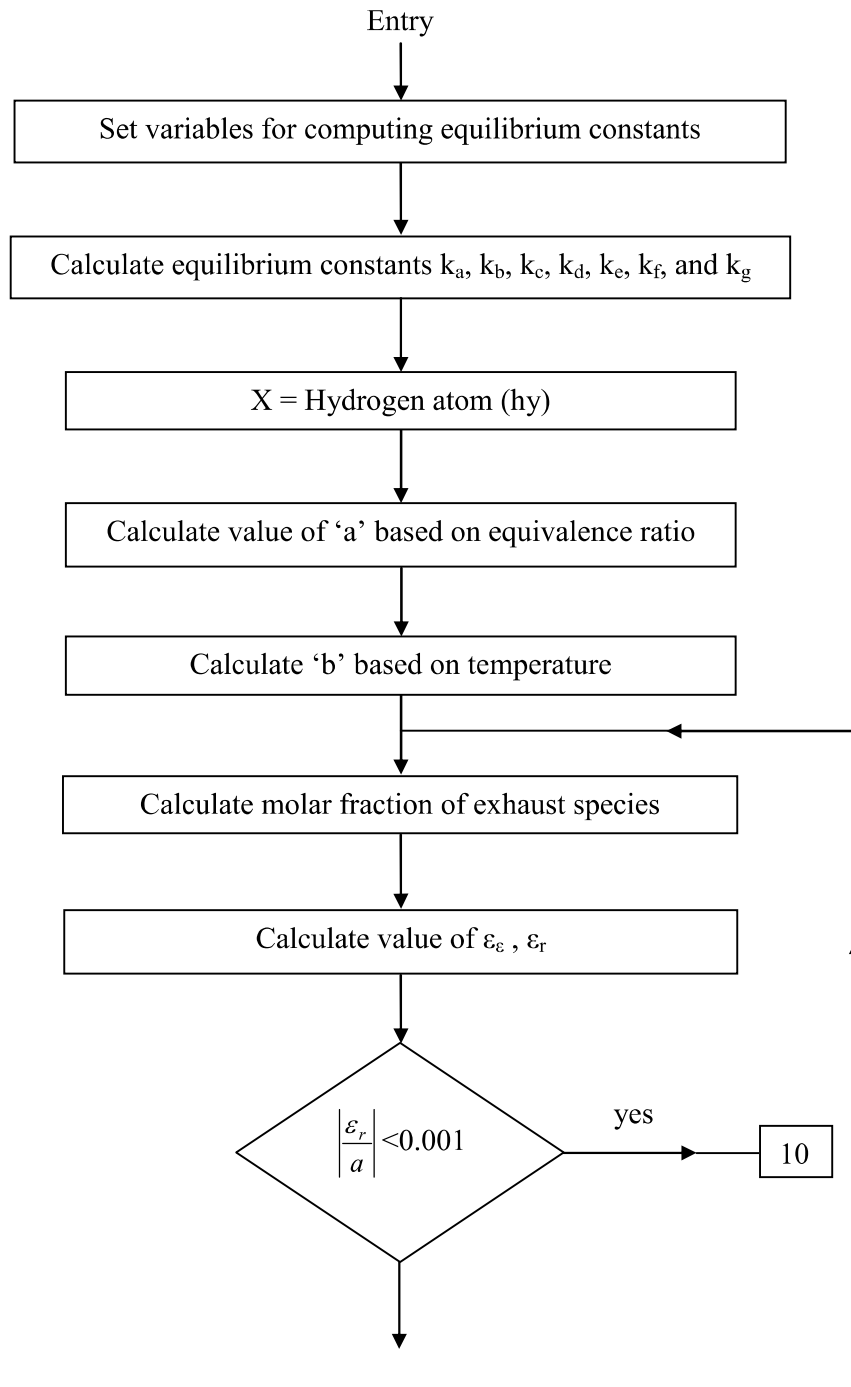


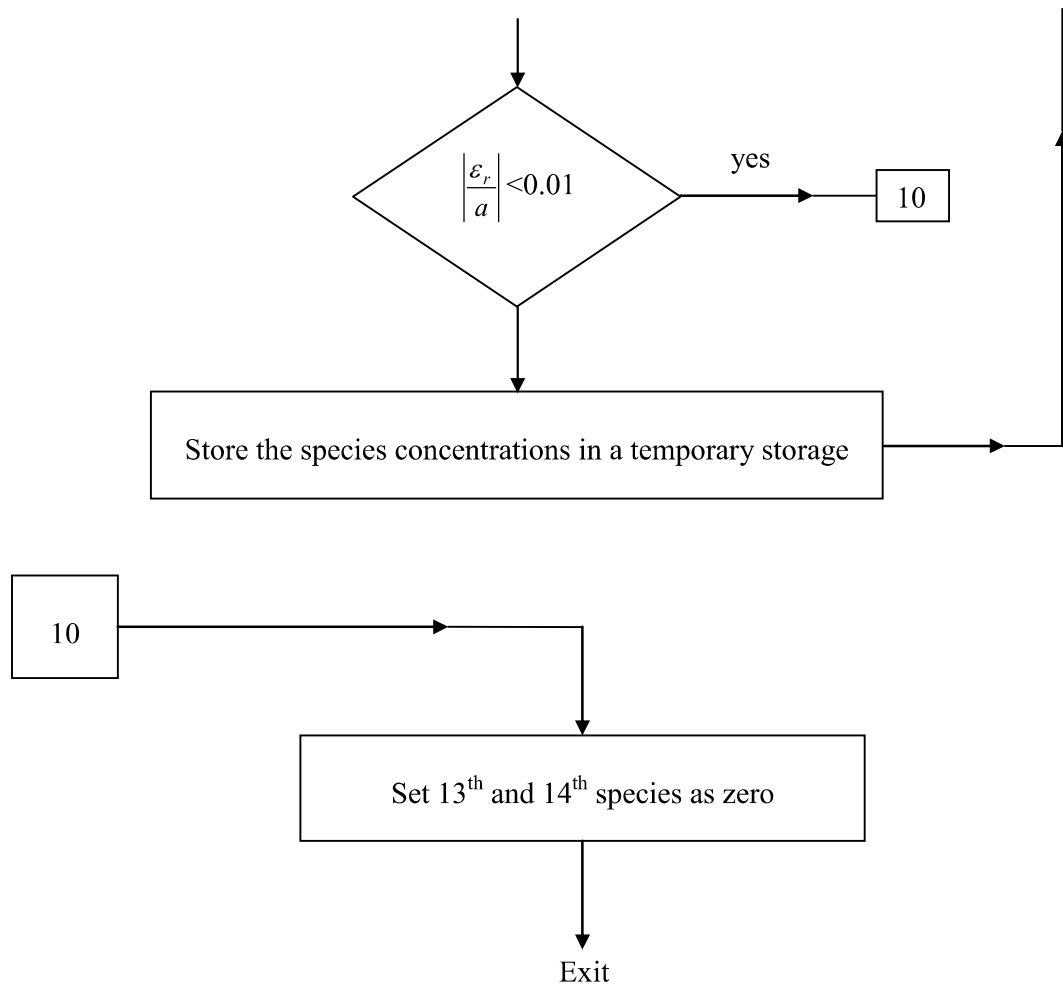




C.2: Flow chart for SUBROUTINE PAREQ

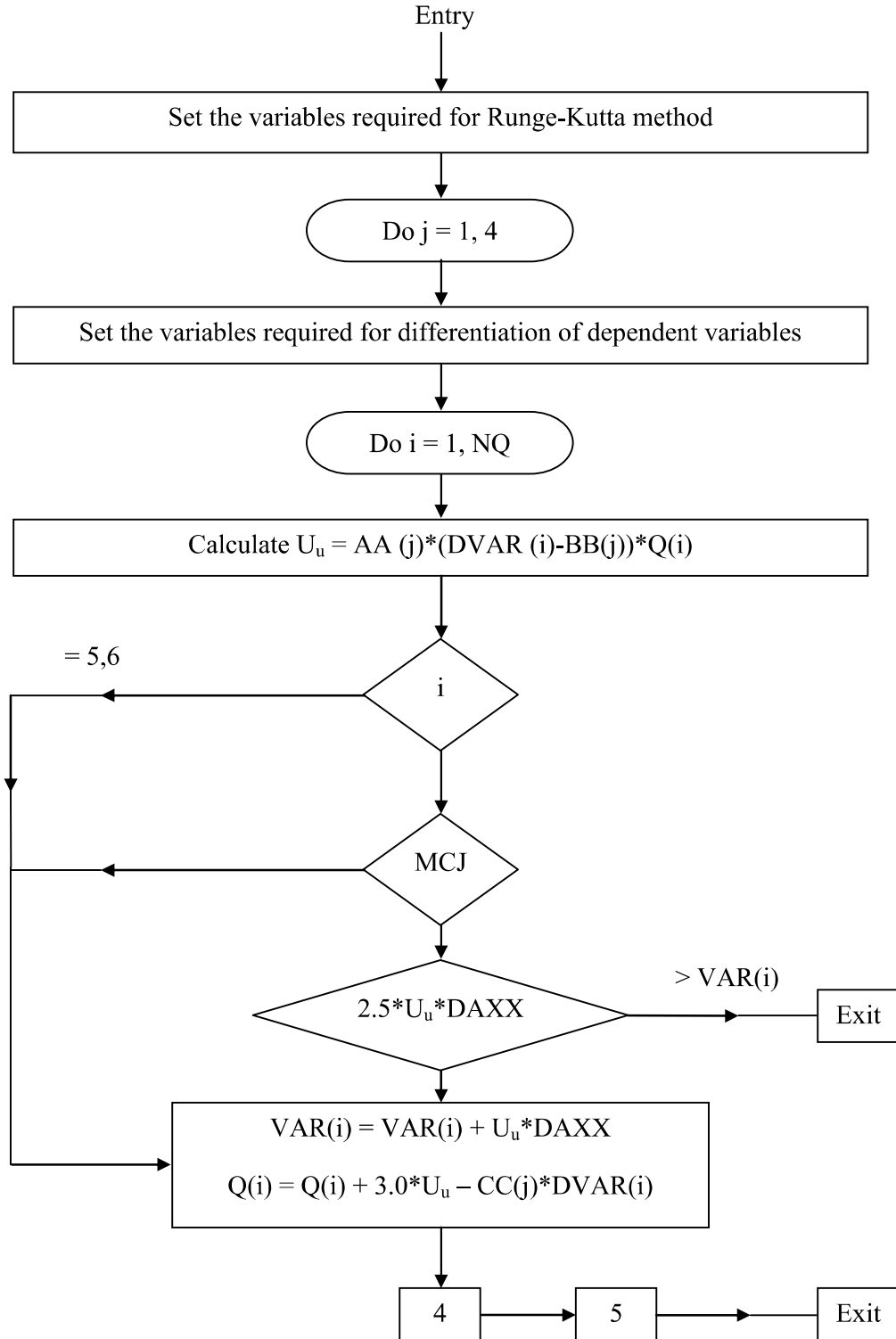
This subroutine calculates the equilibrium thermodynamics.





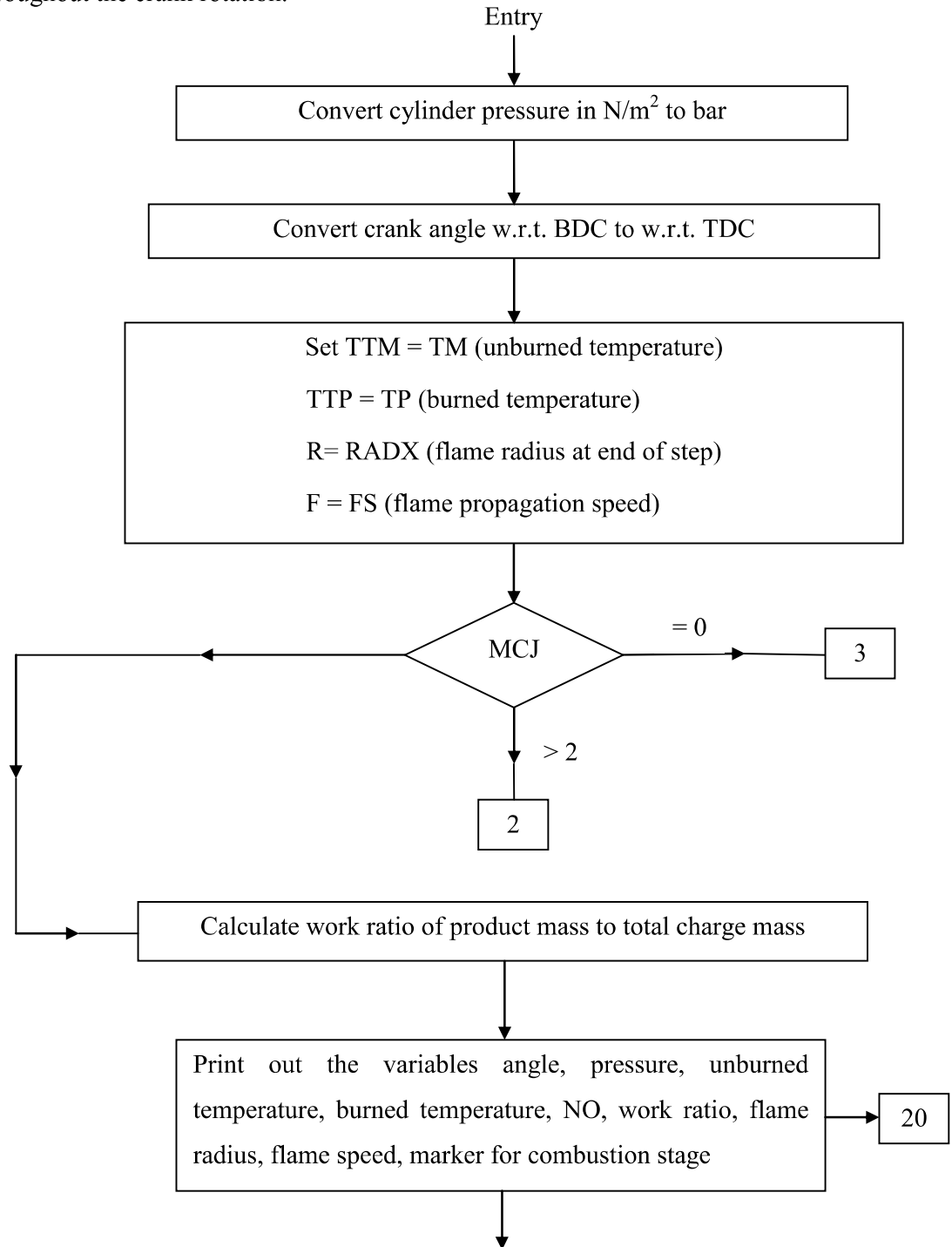
C.3: Flow chart for SUBROUTINE STINT

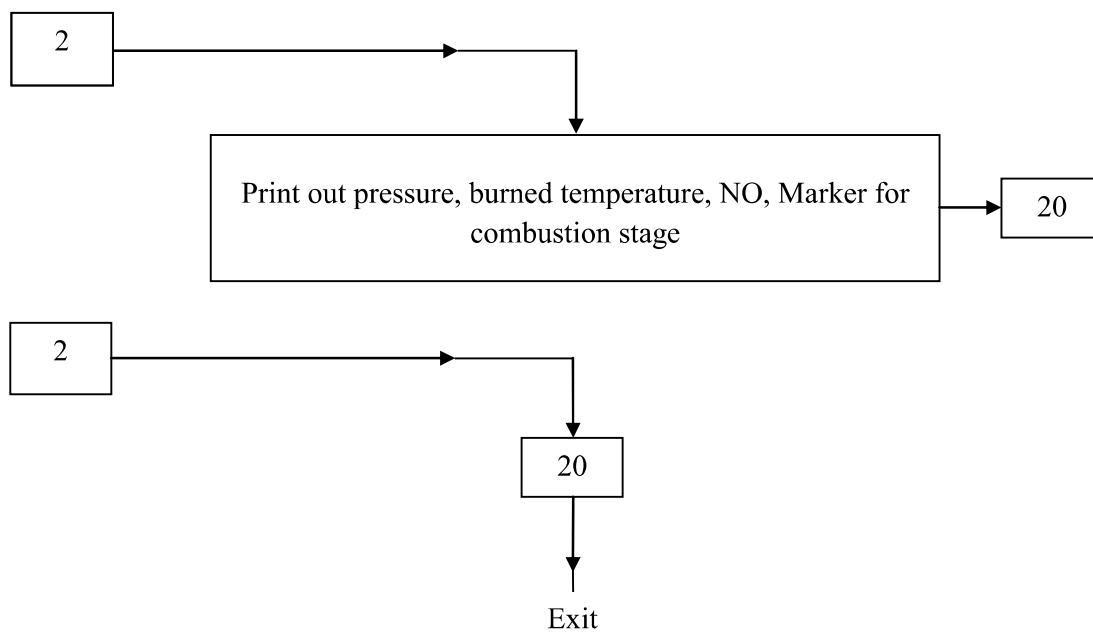
This subroutine is used to steps up the variables by Runge-Kutta method.



C.4: Flow chart for SUBROUTINE SPOUT:

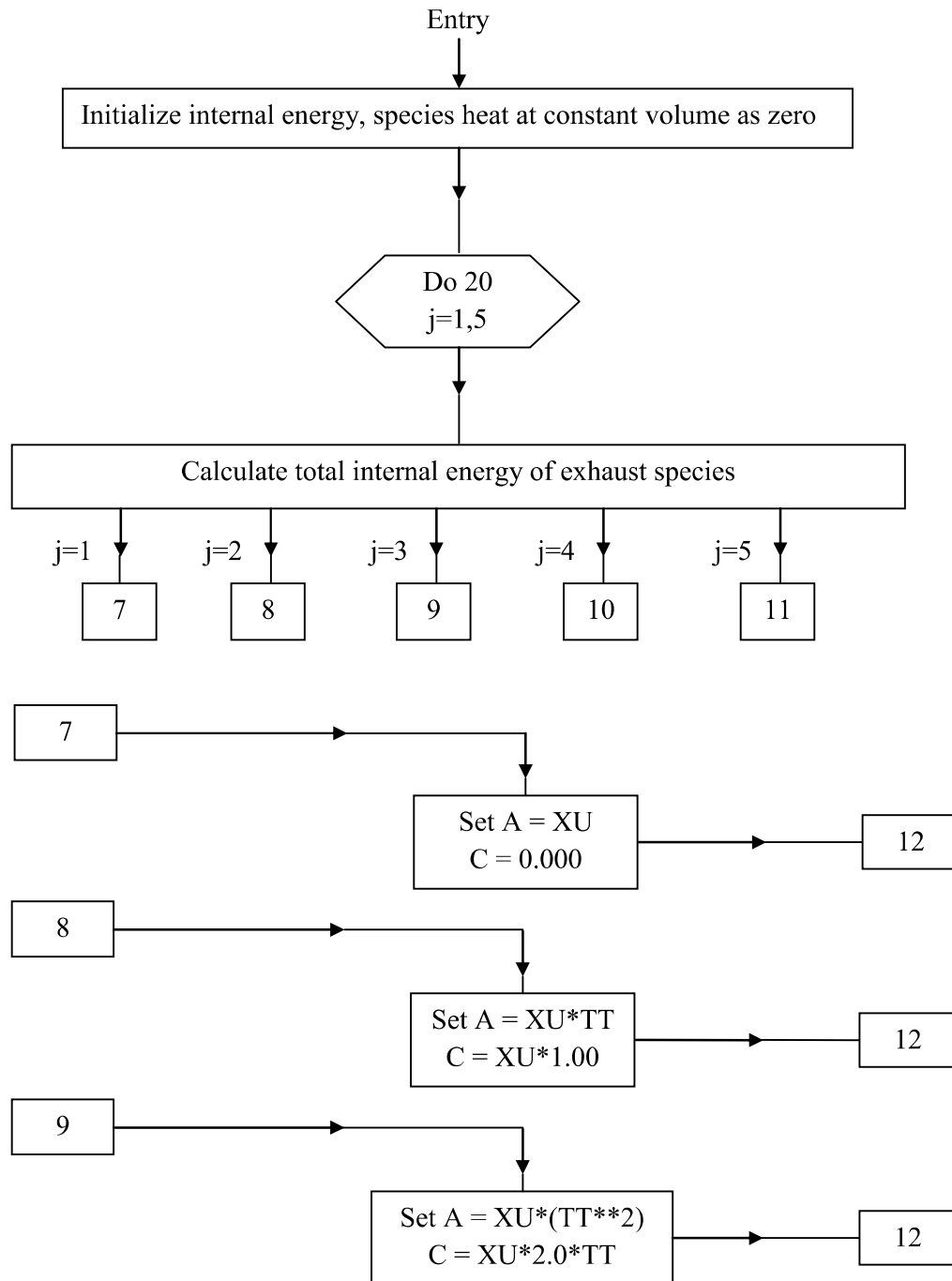
This subroutine is used to print out the variables; cylinder pressure, unburned temperature, burned temperature, NO, work ratio, burning speed, marker for combustion stage throughout the crank rotation.

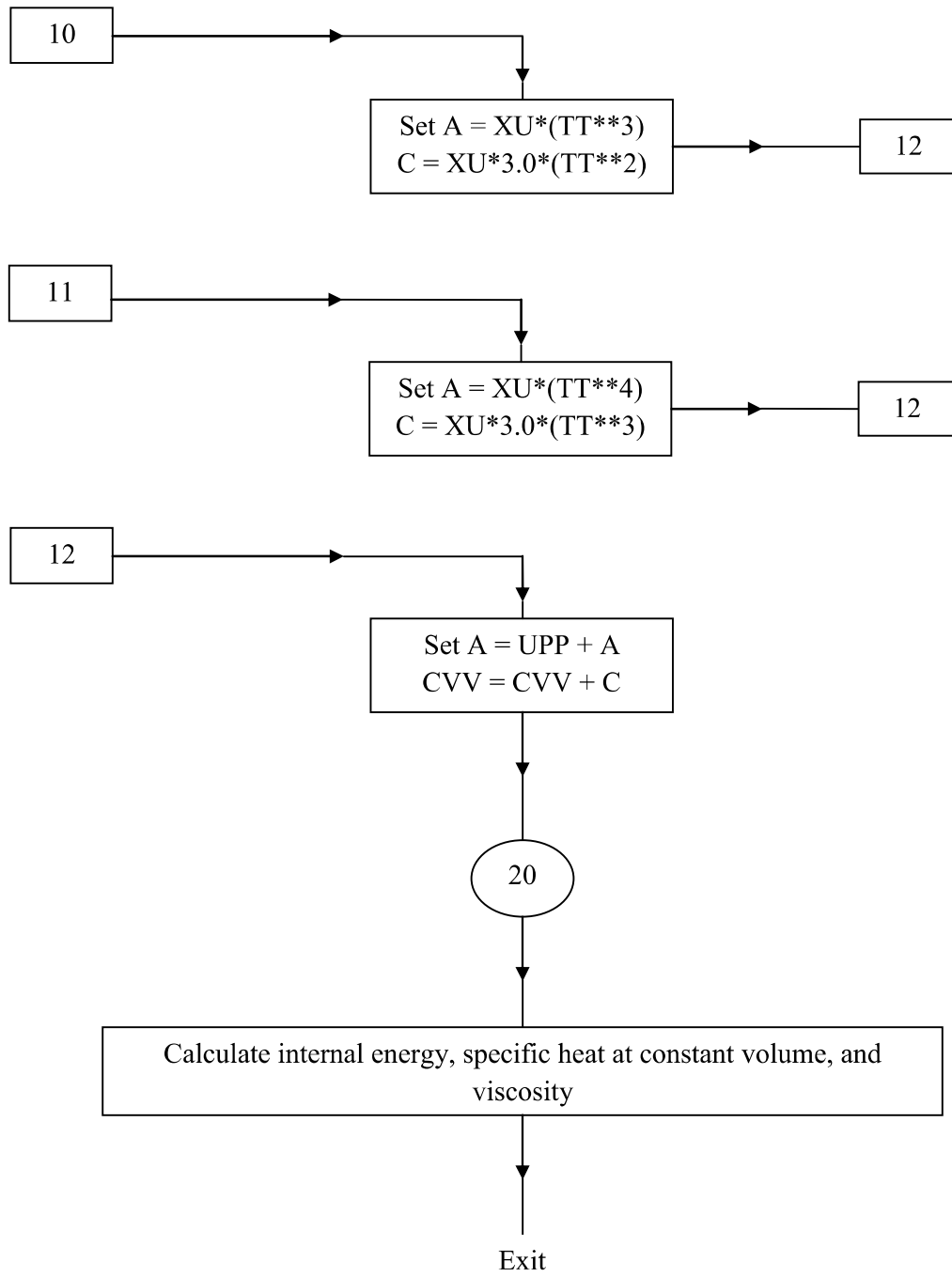




C.5: Flow chart for SUBROUTINE PROPS:

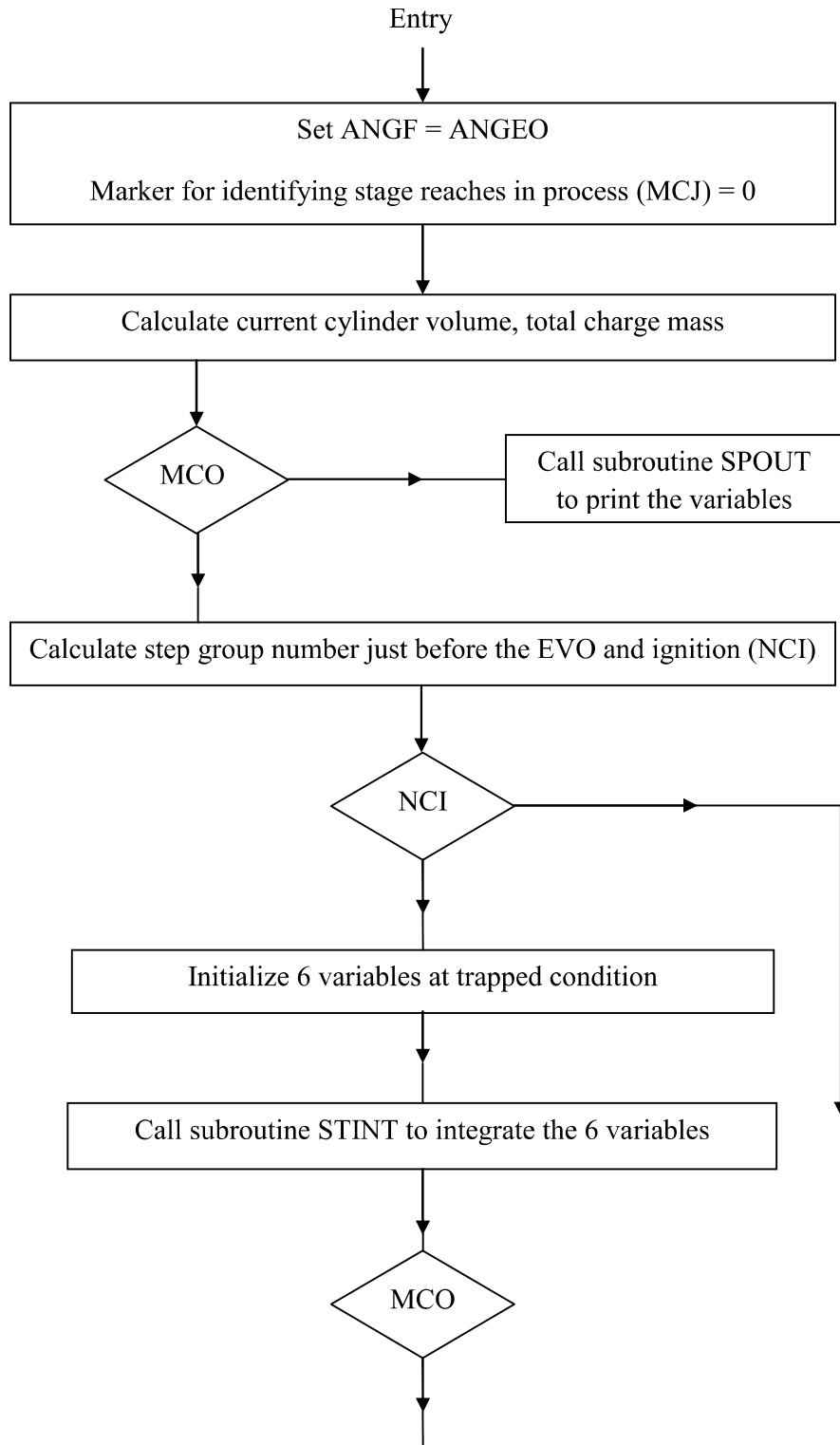
This subroutine calculates the molecular weight of fuel and total molecular weight of all exhaust species.

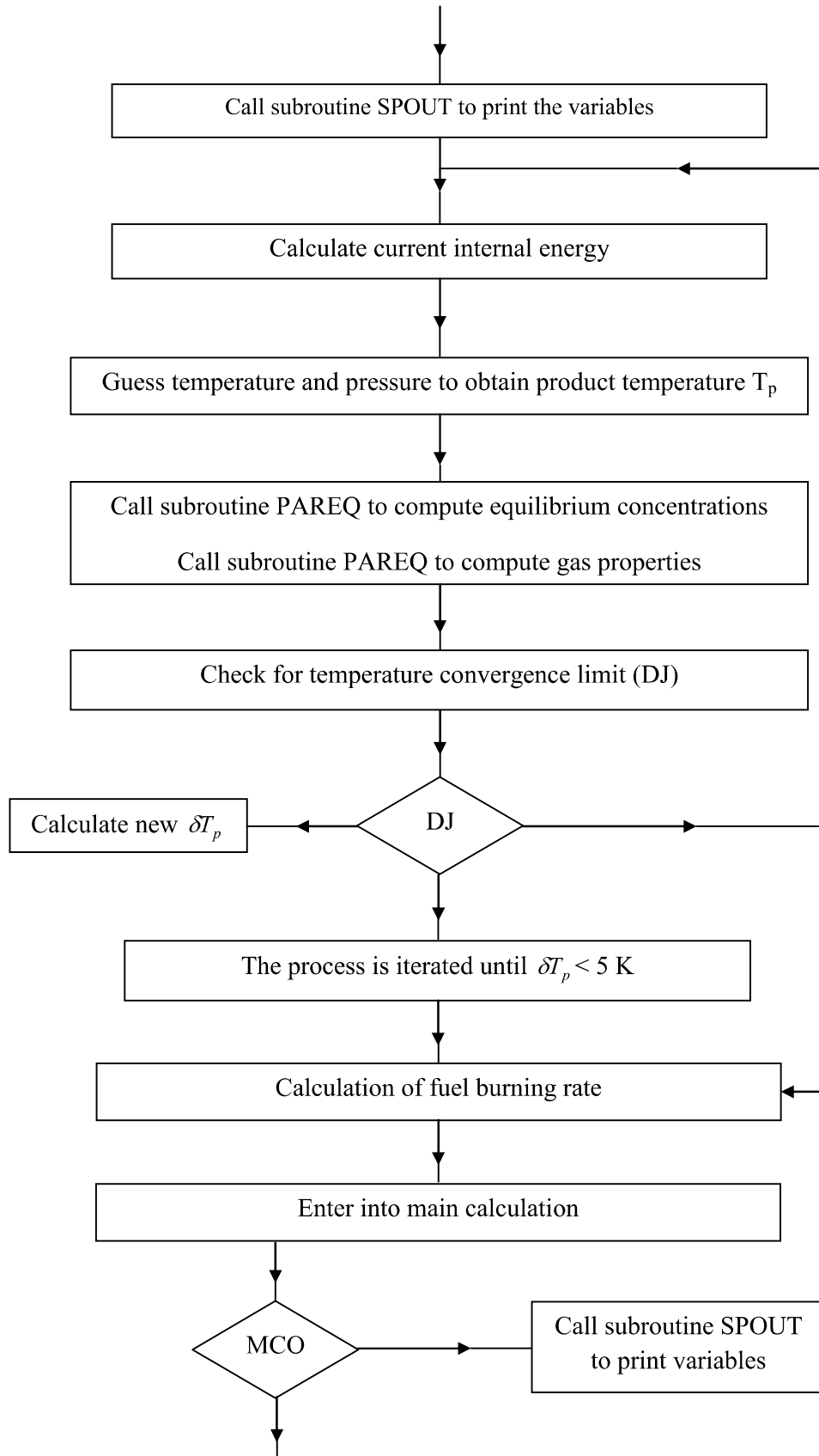


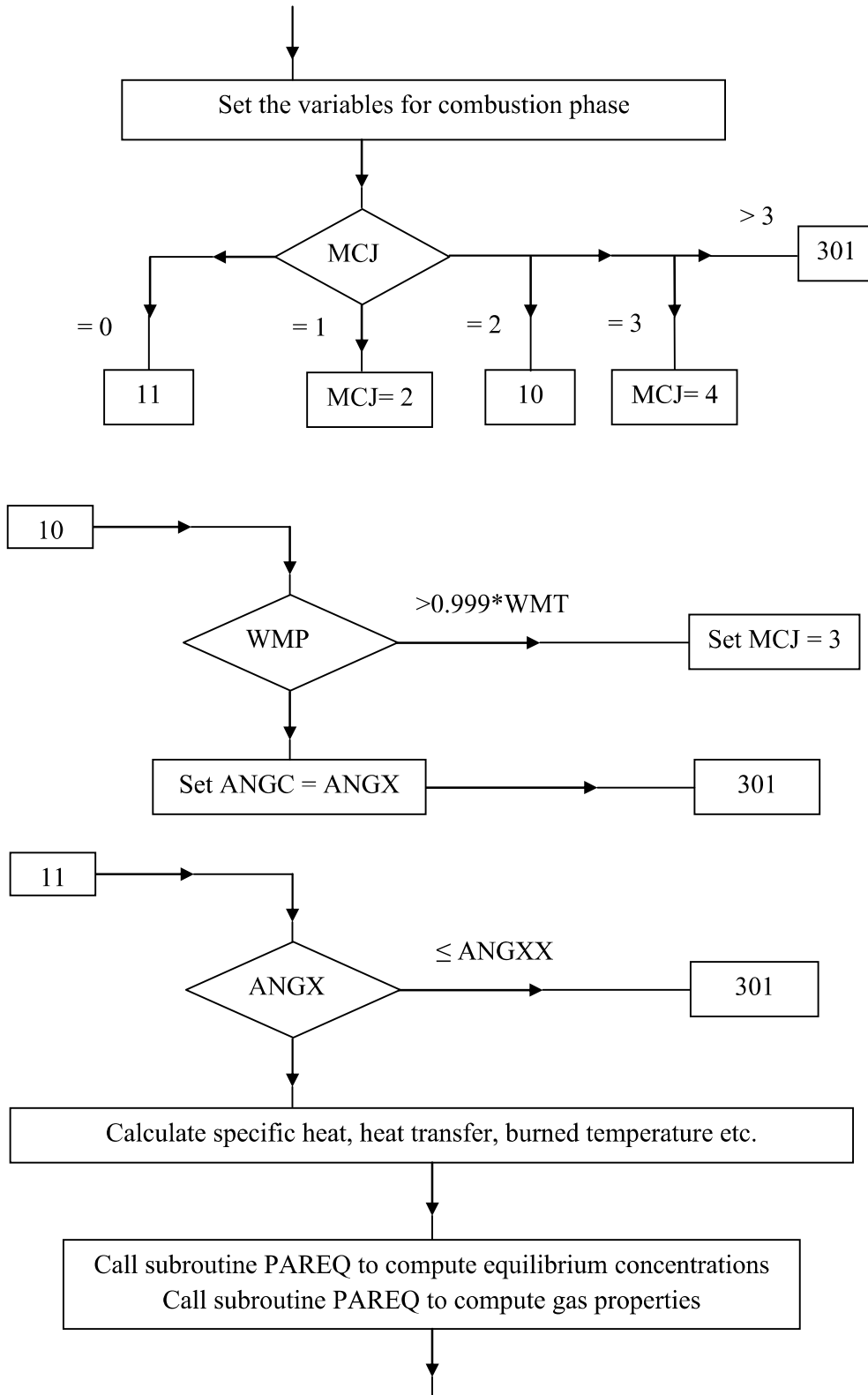


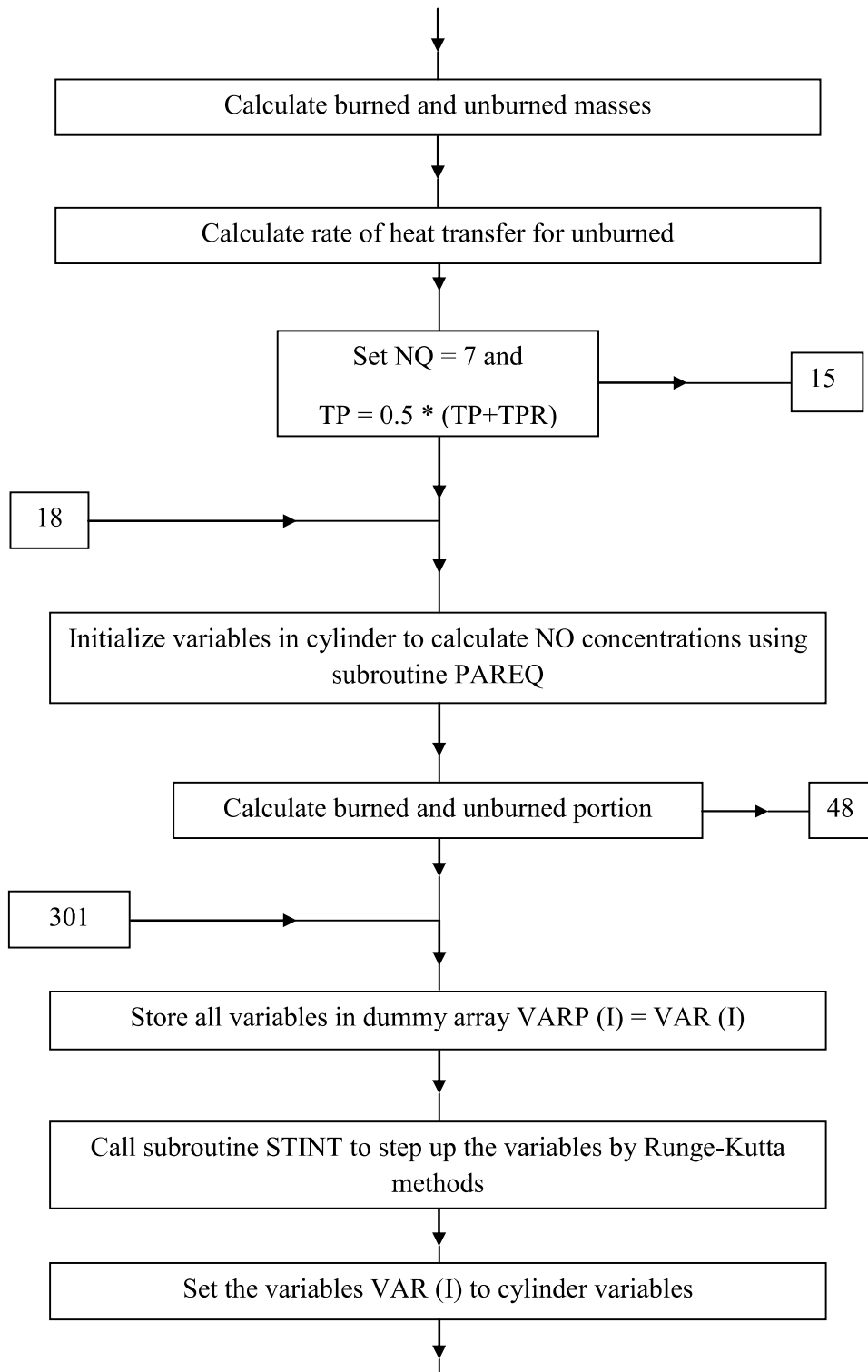
C.6: Flow chart for SUBROUTINE SPIG:

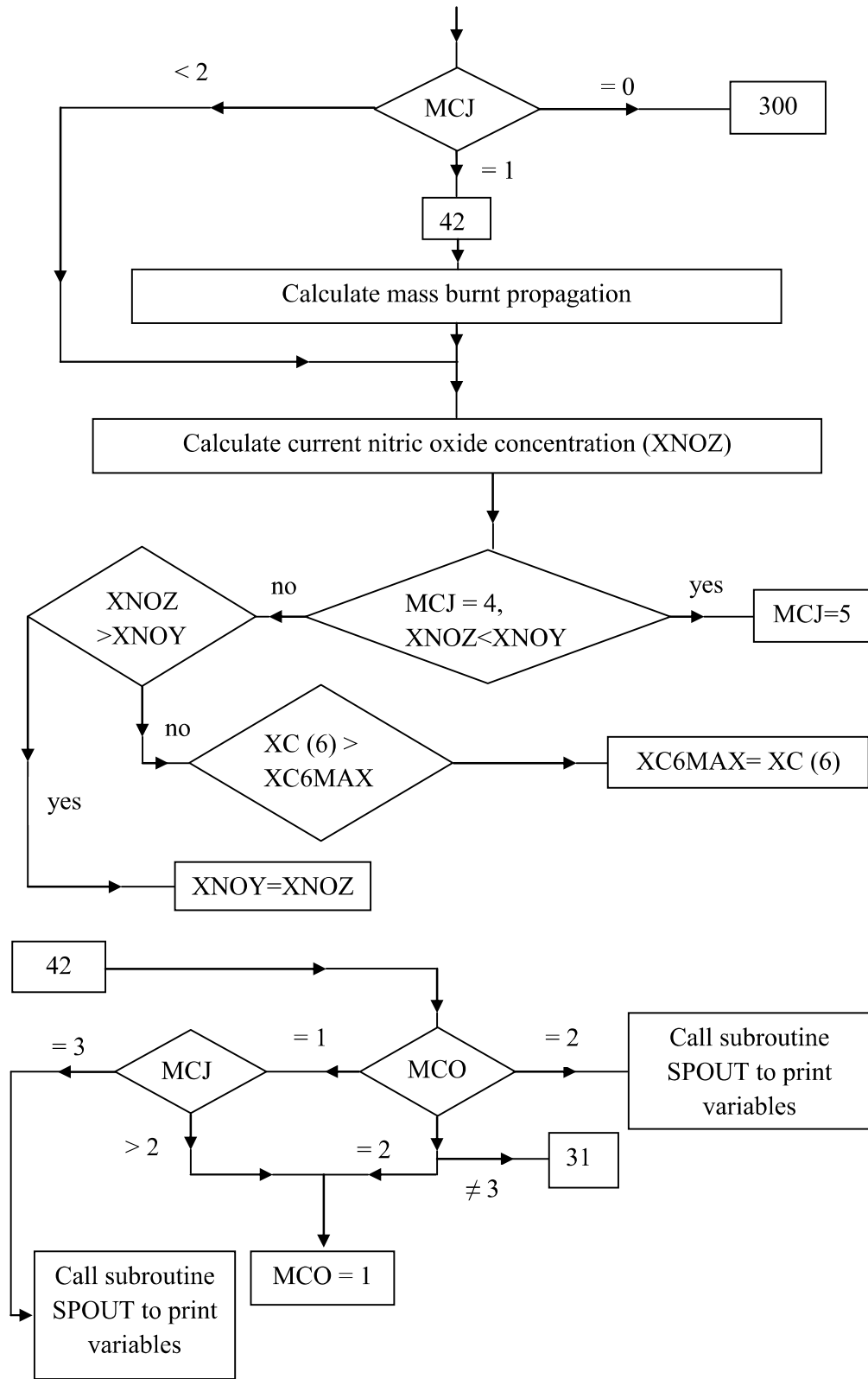
This subroutine calculates the combustion initiation and its progress in the cylinder.

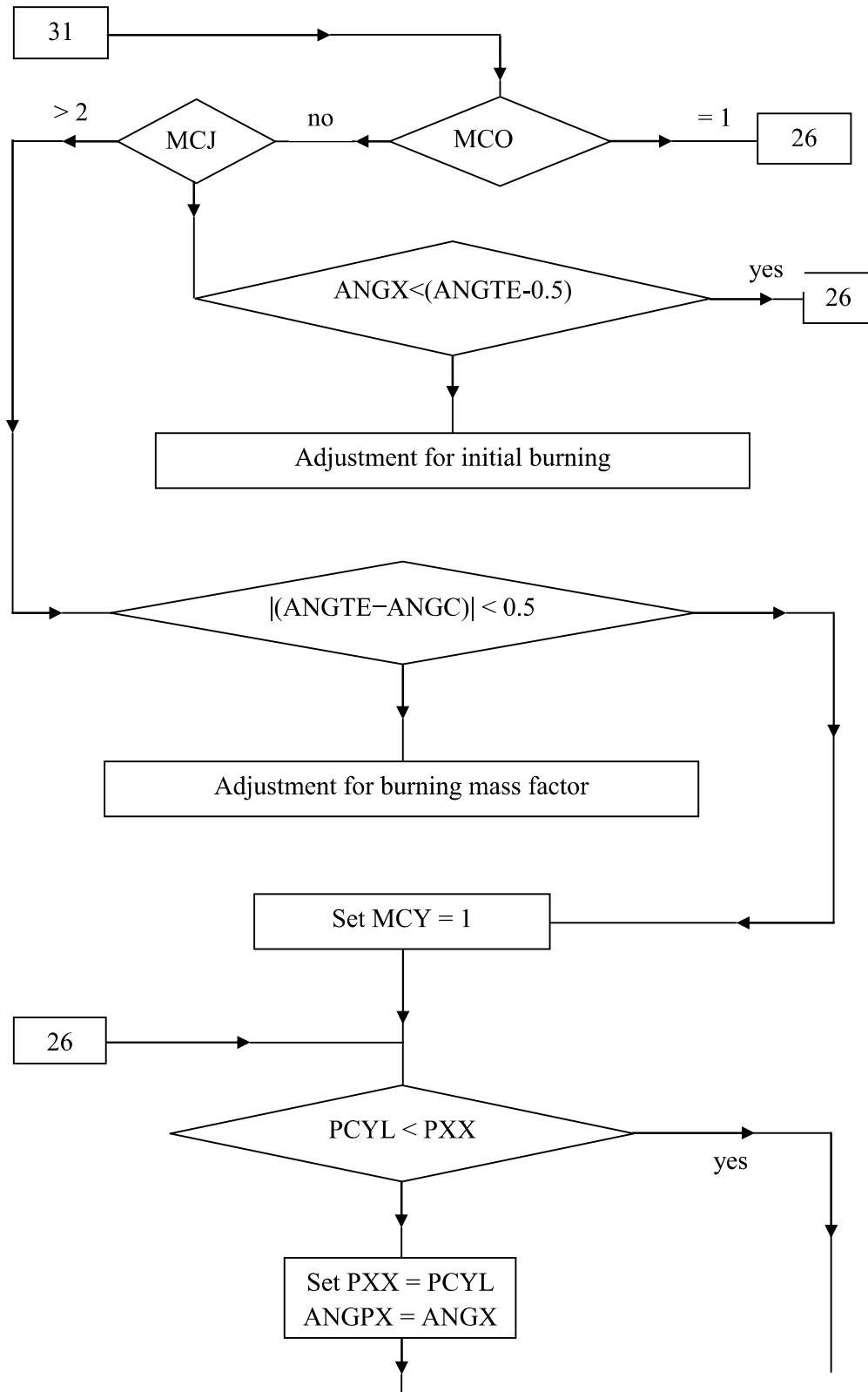


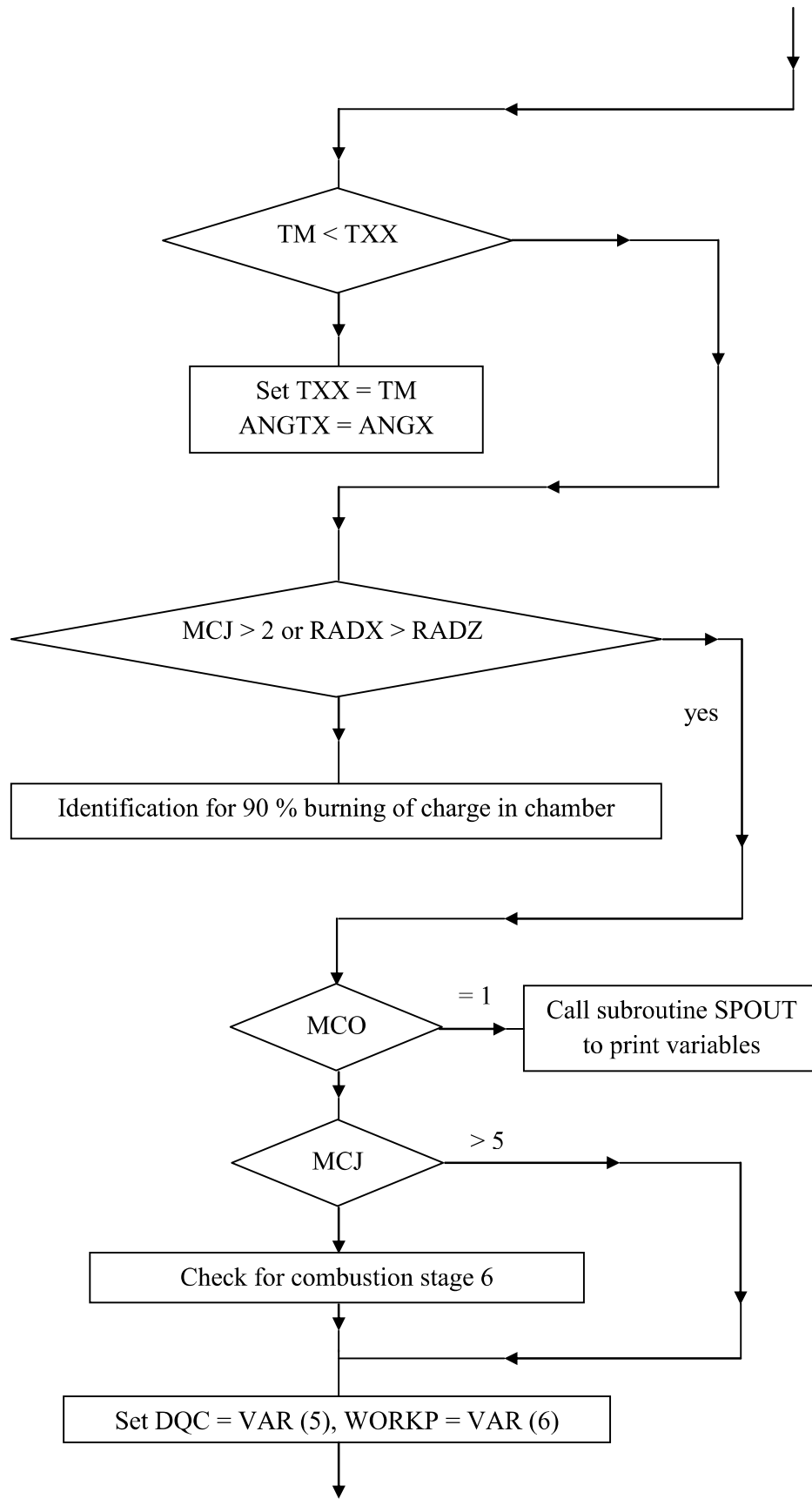












APPENDIX D: SIMULATED RESULTS

Conditions: Equivalence ratio = 0.58, Compression ratio = 18.0, Air fuel ratio = 20.0, $P_{\text{trap}}=1.0$ bar, $T_{\text{trap}}=300.0$ K

Table D.1: Results obtained with the variation of fuel injection timing at engine speed 1500 rpm

Injection timing (CAD)	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	P_{max} (bar)	T_{max} (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
43° bTDC	8.169	7.088	9.885	8.578	0.19016	0.21915	77.068	1003.4	2383.9	86.50	1942.4	0.05
33° bTDC	8.241	7.160	9.972	8.664	0.18851	0.21696	76.754	998.2	2426.9	76.50	1731.4	0.05
23° bTDC	8.305	7.225	10.05	8.743	0.18704	0.21501	76.349	993.1	2475.8	66.50	1549.0	0.04
13° bTDC	8.358	7.278	10.114	8.807	0.18585	0.21345	75.226	986.6	2532.2	56.75	1388.4	0.04
3° bTDC	8.319	7.239	10.067	8.759	0.18673	0.21460	70.652	967.0	2565.9	47.25	1180.0	0.04
7° aTDC	7.963	6.883	9.636	8.328	0.19508	0.22571	58.999	914.0	2547.9	36.37	893.8	0.04

Table D.2: Results obtained with the variation of fuel injection timing at engine speed 2000 rpm

Injection timing (CAD)	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	P _{max} (bar)	T _{max} (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
43° bTDC	11.043	9.423	10.022	8.552	0.18757	0.21981	77.182	1005.8	2382.6	86.50	1576.2	0.05
33° bTDC	11.125	9.505	10.096	8.626	0.18618	0.21791	76.907	1001.2	2425.6	76.50	1417.8	0.05
23° bTDC	11.202	9.582	10.166	8.697	0.18490	0.21616	76.555	997.6	2479.7	66.50	1295.8	0.04
13° bTDC	11.260	9.640	10.219	8.749	0.18395	0.21485	75.238	990.3	2531.9	56.75	1157.6	0.04
3° bTDC	11.172	9.552	10.139	8.669	0.18540	0.21683	70.165	966.9	2566.8	47.25	972.4	0.04
7° aTDC	10.644	9.024	9.660	8.190	0.19459	0.22952	58.037	910.8	2550.0	36.50	722.4	0.04

Table D.3: Results obtained with the variation of fuel injection timing at engine speed 2500 rpm

Injection timing (CAD)	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	P _{max} (bar)	T _{max} (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
43° bTDC	13.941	11.658	10.122	8.464	0.18572	0.22209	77.185	1006.0	2381.6	86.50	1312.8	0.05
33° bTDC	14.028	11.745	10.185	8.527	0.18457	0.22045	77.019	1003.4	2424.7	76.50	1208.9	0.05
23° bTDC	14.116	11.833	10.249	8.592	0.18342	0.21880	76.656	1000.2	2478.5	66.50	1113.8	0.04
13° bTDC	14.181	11.898	10.296	8.638	0.18257	0.21761	75.165	993.2	2531.7	56.75	998.0	0.04
3° bTDC	14.033	11.750	10.188	8.531	0.18451	0.22036	69.641	967.0	2567.4	47.25	834.1	0.04
7° aTDC	13.299	11.016	9.652	7.998	0.19468	0.23503	56.797	909.0	2551.4	36.62	614.1	0.04

Table D.4: Results obtained with the variation of fuel injection timing at engine speed 3000 rpm

Injection timing (CAD)	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	P _{max} (bar)	T _{max} (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
43° bTDC	16.889	13.798	10.218	8.348	0.18396	0.22517	77.195	1006.4	2401.2	82.50	1108.8	0.05
33° bTDC	16.950	13.859	10.255	8.385	0.18330	0.22418	76.970	1003.0	2423.9	76.50	1037.7	0.05
23° bTDC	17.048	13.957	10.315	8.445	0.18225	0.22261	76.660	1001.6	2477.5	66.50	972.2	0.04
13° bTDC	17.109	14.018	10.351	8.481	0.18160	0.22164	75.036	994.5	2531.4	56.75	880.1	0.04
3° bTDC	16.894	13.803	10.222	8.352	0.18391	0.22509	69.069	967.0	2567.8	47.50	734.4	0.04
7° aTDC	15.958	12.867	9.655	7.785	0.19469	0.24146	56.097	905.4	2552.5	36.75	533.7	0.04

Table D.5: Results obtained with the variation of fuel injection timing at engine speed 4000 rpm

Injection timing (CAD)	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	P _{max} (bar)	T _{max} (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
43° bTDC	21.632	16.897	10.333	8.071	0.18193	0.23291	77.491	1005.3	2423.0	77.50	880.3	0.05
33° bTDC	22.525	17.427	10.351	8.008	0.18161	0.23474	76.948	1003.3	2422.9	71.50	832.1	0.05
23° bTDC	22.937	17.714	10.408	8.038	0.18061	0.23387	76.610	1003.4	2475.9	66.50	784.1	0.04
13° bTDC	22.982	17.759	10.429	8.059	0.18026	0.23327	74.705	995.6	2531.1	56.75	718.3	0.04
3° bTDC	22.603	17.381	10.257	7.887	0.18327	0.23835	67.953	965.1	2568.4	47.50	597.7	0.04
7° aTDC	21.203	15.980	9.621	7.251	0.19538	0.25924	54.422	899.4	2554.1	37.00	429.1	0.04

Table D.6: Results obtained with the variation of Stroke/Bore ratios at engine speed 1500 rpm

Stroke/Bore ratios	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	Pmax (bar)	Tmax (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
0.50	3.1988	2.7691	9.7324	8.4249	0.19080	0.2204	76.272	969.7	2477.8	66.50	1356.7	0.04
0.75	4.8700	4.2254	9.8780	8.5705	0.1887	0.2175	76.401	980.3	2477.1	66.50	1468.9	0.04
1.00	6.5563	5.6967	9.9736	8.6661	0.1877	0.2160	76.374	987.0	2476.4	66.50	1523.2	0.04
1.25	8.2571	7.1827	10.0487	8.7413	0.1870	0.2150	76.352	993.0	2475.8	66.50	1548.5	0.04
1.50	9.9670	8.6777	10.1081	8.8006	0.1867	0.2144	76.274	997.4	2475.1	66.50	1554.4	0.04
1.75	11.6868	10.1827	10.1591	8.8516	0.1865	0.2141	76.194	1001.0	2474.5	66.50	1547.6	0.04
2.00	13.4157	11.6967	10.2042	8.8967	0.1865	0.2139	76.152	1004.6	2478.6	66.50	1548.1	0.04

Table D.7: Results obtained with the variation of Stroke/Bore ratios at engine speed 2000 rpm

Stroke/Bore ratios	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	P _{max} (bar)	T _{max} (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
0.50	4.3195	3.6753	9.8565	8.3865	0.1884	0.2214	76.566	975.5	2477.3	66.50	1160.0	0.04
0.75	6.5717	5.6054	9.9971	8.5271	0.1865	0.2186	76.676	985.8	2476.5	66.50	1243.4	0.04
1.00	8.8447	7.5563	10.091	8.6211	0.1855	0.2171	76.633	992.3	2475.7	66.50	1278.9	0.04
1.25	11.137	9.5263	10.165	8.6951	0.1849	0.2162	76.558	997.4	2479.8	66.50	1295.4	0.04
1.50	13.440	11.508	10.223	8.7528	0.1846	0.2156	76.445	1001.2	2478.7	66.50	1293.3	0.04
1.75	15.757	13.502	10.273	8.8029	0.1845	0.2153	76.333	1004.4	2477.6	66.50	1281.9	0.04
2.00	18.089	15.512	10.319	8.8490	0.1844	0.2150	76.172	1006.5	2476.6	66.50	1255.0	0.04

Table D.8: Results obtained with the variation of Stroke/Bore ratios at engine speed 2500 rpm

Stroke/Bore ratios	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	Pmax (bar)	Tmax (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
0.50	5.4509	4.5429	9.9505	8.2930	0.1866	0.2239	76.843	981.1	2476.8	66.50	1023.7	0.04
0.75	8.2870	6.9251	10.085	8.4277	0.1849	0.2212	76.868	989.9	2476.0	66.50	1083.1	0.04
1.00	11.150	9.3344	10.177	8.5199	0.1839	0.2197	76.792	995.8	2479.8	66.50	1111.6	0.04
1.25	14.034	11.7641	10.247	8.5900	0.1834	0.2188	76.659	1000.1	2478.5	66.50	1113.5	0.04
1.50	16.936	14.212	10.306	8.6481	0.1831	0.2182	76.495	1003.3	2477.3	66.50	1102.0	0.04
1.75	19.855	16.677	10.356	8.6982	0.1830	0.2179	76.297	1005.5	2476.2	66.50	1080.8	0.04
2.00	22.788	19.15589	10.39968	8.74218	0.182961	0.217651	76.144	1007.7	2475.1	66.50	1061.5	0.04

Table D.9: Results obtained with the variation of Stroke/Bore ratios at engine speed 3000 rpm

Stroke/Bore ratios	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	P _{max} (bar)	T _{max} (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
0.50	6.5884	5.3591	10.022	8.1524	0.1853	0.2277	77.009	984.7	2476.5	66.50	917.9	0.04
0.75	10.012	8.2839	10.154	8.1683	0.1836	0.2251	77.001	992.8	2480.2	66.50	968.3	0.04
1.00	13.467	11.009	10.244	8.3737	0.1827	0.2236	76.872	998.1	2478.8	66.50	980.1	0.04
1.25	16.946	13.873	10.312	8.4419	0.1823	0.2227	76.698	1001.8	2477.5	66.50	977.3	0.04
1.50	20.448	16.760	10.369	8.4986	0.1820	0.2221	76.500	1004.6	2476.3	66.50	963.7	0.04
1.75	23.968	19.666	10.418	8.5476	0.1819	0.2217	76.273	1006.5	2475.0	66.50	942.7	0.04
2.00	27.507	22.560	10.461	8.5911	0.1819	0.2215	76.017	1007.8	2473.8	66.75	916.6	0.04

Table D.10: Results obtained with the variation of Stroke/Bore ratios at engine speed 4000 rpm

Stroke/Bore ratios	IP (kW)	BP (kW)	IMEP (bar)	BMEP (bar)	ISFC (kg/kWh)	BSFC (kg/kWh)	P _{max} (bar)	T _{max} (K)		Combustion Duration (degree)	NO (ppm)	CO (%)
								Un-burned	Burned			
0.50	8.8791	6.8019	10.130	7.7604	0.1833	0.2393	77.233	989.8	2480.6	66.50	771.2	0.04
0.75	13.482	10.366	10.255	7.8847	0.1818	0.2364	77.132	996.7	2479.0	66.50	797.2	0.04
1.00	18.127	13.973	10.341	7.9709	0.1810	0.2349	76.897	1000.7	2477.4	66.50	796.0	0.04
1.25	22.803	17.610	10.406	8.0365	0.1806	0.2339	76.612	1003.3	2476.0	66.50	784.0	0.04
1.50	27.506	21.274	10.461	8.0906	0.1804	0.2333	76.340	1005.3	2474.6	66.75	768.8	0.04
1.75	32.233	24.962	10.507	8.1372	0.1803	0.2329	76.040	1006.7	2473.2	66.75	748.8	0.04
2.00	36.982	28.673	10.548	8.1785	0.1804	0.2326	75.712	1007.5	2471.9	66.75	725.7	0.04

