PONTIFICIA UNIVERSIDAD CATÓLICA DEL PERÚ

FACULTAD DE CIENCIAS E INGENIERÍA

ANEXOS

DETERMINACIÓN DE LA VELOCIDAD DE LLAMA LAMINAR EN UN QUEMADOR DE PREMEZCLA

Tesis para optar el Título de Ingeniero Mecánico, que presenta el bachiller:

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Lima, Abril 2015

ANEXO 1

Documentación del programa NASA Lewis 89 (NL89) usado para la determinación de la temperatura de llama adiabática.

THE NASA-Lewis THERMODYNAMIC EQUILIBRIUM CODE

References: R.A. Svehla and B.J. McBride, "FORTRAN IV Computer Program for Calculation of Thermodynamic and Transport Properties of Complex Chemical Systems", NASA TND-7056 (1973)

S. Gordon and B.J. McBride. "Computer Program for Complex Chemical Equilibrium Compositions, Rocket Performance, Incident Shocks, and Chapman-Jouguet Detonations", NASA SP-273, Interim Revision, March 1976.

PC VERSION

* This PC version is based on the 1989 version of the NASA-Lewis code, CET89 (reference TM-86885, TM-100785, and above).

* This version contains BRL (US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD 21005-5066) modifications for the PC. It is, however, a complete implementation of CET89.

* This PC version is not supported by NASA-Lewis or the above authors. All inquiries should be directed to the BRL, POC: Dr. Anthony J. Kotlar (301)278-6128 or Dr. Jeffrey B. Morris (301)278-6806.

* This program and data base, or any portions thereof, may not be sold for profit.

********** NL89 **********

NL89.EXE

REQUIRES ABOUT 440KB USER AVAILABLE MEMORY WITH MAX(NS=400, NC=300)
80X87 COPROCESSOR REQUIRED
COMPILED USING MICROSOFT FORTRAN VERSION 5.1

If the binary database has not already been created, this must be done before performing any calculations. To create the binary database using the provided library file, run

NL89 LIBRARY.IN

where LIBRARY.IN contains the ASCII database. Any other file may be designated as long as it contains a valid ASCII database. The "binary", i.e. unformatted, version of the library, which is used by NL89, is contained by default in the files THERMO.BIN and TRANS.BIN, for the thermodynamic and transport data respectively. Once these files are made, it is only necessary to do a "library" run if the data base is modified.

To run a test case type

NL89 TEST_NL.IN

or

NL89 TEST.IN

To run any job [path]filename[.ext] run

NL89 [path]filename[.ext]

The output is in the same directory as the input file; it has the same filename with the extension .OUT, unless otherwise specified as indicated by NL89.

If the input file is not included on the command line, MS-FORTRAN issues the message

File name missing or blank - please enter file name
UNIT 5?

The input filename may then be entered.

********** IMPORTANT NOTE **********
The & must be used to designate the NAMELIST. The list must end with a /. The list parameters must not have a blank space after the parameter value if it is followed by another parameter on the same line, i.e.,

IONS=T, hp=t /

will work, but

IONS=T , hp=t /

will cause immediate termination of the job because of the space after IONS=T. This appears to be a peculiarity of Microsoft FORTRAN's implementation of NAMELIST. See the sample test files.

_____FILE SUMMARY_____

_SOURCE.EXE is a packed file containing the source code. Run _SOURCE to unpack the files. The contents are:
*.FOR files containing the FORTRAN source code;
LNASA.BAT is the link sequence.

LIBRARY.IN is the complete database (thermodynamic & transport) for CET89.

TRIAL is a sample calculation.

TEST.IN is another example of an input file.

TEST_NL.IN is the sample input for CET89 from NASA-Lewis.

Typical run times for two classes of PCs:

	386/25MHz	286/8MHz
LIBRARY.IN	19 sec.	2 min.
TRIAL	4 sec.	22 sec.
TEST.IN	4 sec.	22 sec.
TEST_NL	4 min.	23 min.

///// REVISIONS MADE AFTER THE ORIGINAL BRL VERSION OF 11-MAR-91 /////

15-MAR-91 : CET89 allows 16 character species names, but the input field on OMIT records is only 15 characters. Only the allowed 15 characters on OMIT records are used for searches; the full 16 character names are retained in the database and for output.

Two new control codes, NOTE and !, are added to permit the insertion of notes, comments, titles, etc. in the input file. A NOTE is echoed to the screen and the output file; a ! is not printed. Any number of NOTE or ! statements may be included where a control code record in the input is allowed. The record, including the word NOTE, may be a total of 75 characters; any additional characters on the line are not read or printed. See the file TRIAL for examples.

11-APR-91 : The 00 in columns 37-38 that were omitted (in some versions) from two of the sample input files, TRIAL and TEST.IN, are restored. These flags are needed in order to have the program calculate the heat of formation from the information in the thermodynamic database.

12-APR-91 : Found bug in CET89; reported to NASA-Lewis and corrected as recommended by them. Misalignment of variables in SUBROUTINE TRANP caused spurious values for some transport properties.

3-JUL-91 : NL89 now uses the INCLUDE file MAXDIM.NL to globally set the maximum dimensions for NS and NC. See file MAXDIM.NL which is packed in _SOURCE.EXE. The default values are those used in the original CET89. Choose smaller values, recompile all modules and link to produce a smaller executable program.

1-NOV-91 : A problem was encountered for TP=T where T=298.15. The second line of LIBRARY.IN was changed from
298.150 1000.000 5000.000 to
300.000 1000.000 5000.000 solving the problem. Another,

lightly smaller version of the thermo library that shipped with CET89, had 300.000 rather than 298.150. LIBRARY.IN now uses 300.000.

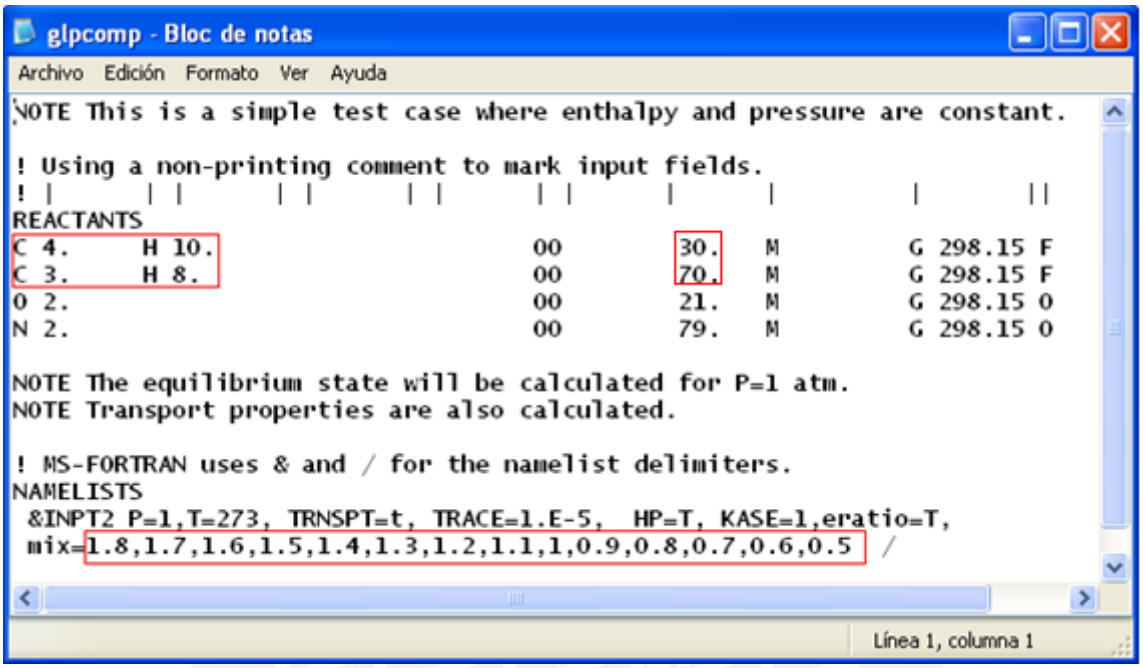
13-NOV-91 : With this revision, the maximum dimensions for NS and NC are now set to 400 and 200 respectively; the original values in CET89 were 600 and 400. The smaller maximum dimensions should be sufficient for most cases. The smaller dimensions are intended to eliminate memory requirement problems that may have been encountered in getting the originally dimensioned version to fit in the user available portion of the basic DOS 640kb. The dimension information for the NL89.EXE is echoed to the screen after the logo. As noted above, users may set the dimensions as required for their application by adjusting two parameters in MAXDIM.NL, compiling all the modules, and linking. MS-FORTRAN Ver. 5.1 is now used for the NL89.EXE included with this package.

********** END - NL89 DOCUMENTATION **********

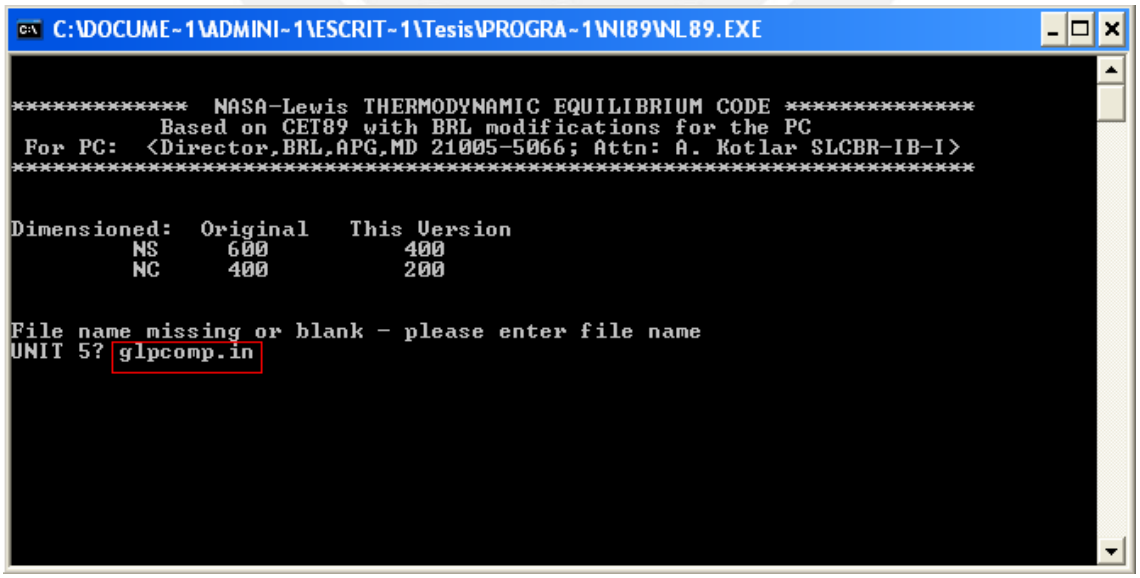
ANEXO 2

Ejemplo de cálculo en el software NL89

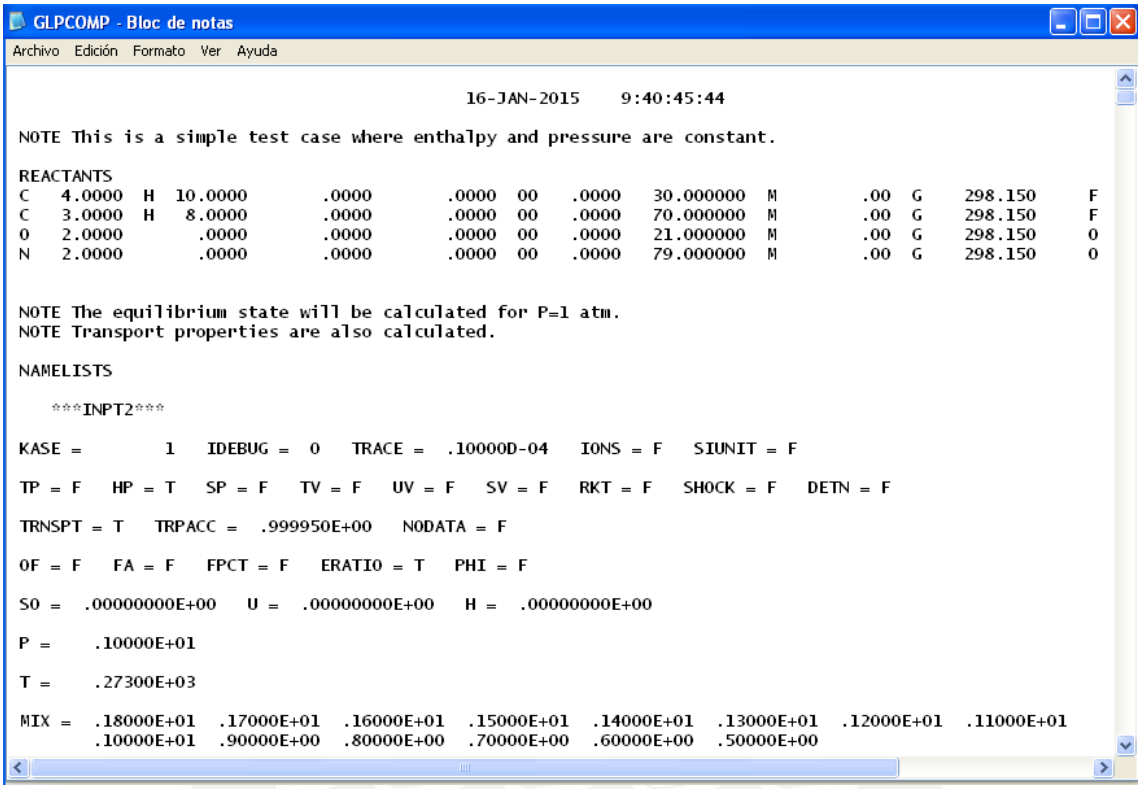
Se debe abrir un archivo de extensión ".in", en este caso se crea el archivo glpcomp.in en donde a la mano izquierda se puede editar los reactantes. Se colocan los números atómicos de las especies evaluadas para el caso del propano, butano y aire. Luego a la derecha se colocan las concentraciones respectivas de la sustancia. Por último en la parte inferior de la fracción estequiométrica "mix" se debe colocar las fracciones que se desean estudiar separadas por comas.



El siguiente paso es abrir el programa NL89.exe y entrar el nombre del archivo que se desea calcular. En nuestro caso se coloca "glpcomp.in" y se le da enter.



Finalmente el programa creará un archivo con el nombre “glpcomp.out”, el cual también se puede abrir como block de notas en donde están las propiedades para cada caso de fracciones estequiométricas que ingresamos en la primera pantalla.



ANEXO 3

TERMODINAMICA 2
COMBUSTION

CAMBIO DE ENTALPIA PARA DIFERENTES SUSTANCIAS $(h_T - h_{298})$

Temp.	CO_2	CO	H_2O	N_2	O_2	H_2
K	kJ/kmol	kJ/kmol	kJ/kmol	kJ/kmol	kJ/kmol	kJ/kmol
100	- 6 456	- 5 770	- 6 615	- 5 770	- 5 778	- 5 293
200	- 3 414	- 2 858	- 3 280	- 2 858	- 2 866	- 2 770
300	67	54	63	54	54	54
400	4 008	2 975	3 452	2 971	3 029	2 958
500	8 314	5 929	6 920	5 912	6 088	5 883
600	12 916	8 941	10 498	8 891	9 247	8 812
700	17 761	12 021	14 184	11 937	12 502	11 749
800	22 815	15 175	17 991	15 046	15 841	14 703
900	28 041	18 397	21 924	18 221	19 246	17 682
1000	33 405	21 686	25 978	21 460	22 707	20 686
1100	38 894	25 033	30 167	24 757	26 217	23 723
1200	44 484	28 426	34 476	28 108	29 765	26 794
1300	50 158	31 865	38 903	31 501	33 351	29 907
1400	55 907	35 338	43 447	34 936	36 966	33 062
1500	61 714	38 848	48 095	38 405	40 610	36 267
1600	67 580	42 384	52 844	41 903	44 279	39 522
1700	73 492	45 940	57 685	45 430	47 970	42 815
1800	79 442	49 522	62 609	48 982	51 689	46 150
1900	85 429	53 124	67 613	52 551	55 434	49 522
2000	91 450	56 739	72 689	56 141	59 199	52 932
2100	97 500	60 375	77 831	59 748	62 986	56 379
2200	103 575	64 019	83 036	63 371	66 802	59 860
2300	109 671	67 676	88 295	67 007	70 634	63 371
2400	115 788	71 346	93 604	70 651	74 492	66 915
2500	121 926	75 023	98 964	74 312	78 375	70 492
2600	128 085	78 714	104 370	77 973	82 274	74 090
2700	134 256	82 408	109 813	81 659	86 199	77 718
2800	140 444	86 115	115 294	85 345	90 144	81 370
2900	146 645	89 826	120 813	89 036	94 111	85 044
3000	152 862	93 542	126 361	92 738	98 098	88 743
3200	165 331	100 998	137 553	100 161	106 127	96 199
3400	177 849	108 479	148 854	107 608	114 232	103 738
3600	190 405	115 976	160 247	115 081	122 399	111 361
4000	215 635	131 026	183 280	130 076	138 913	126 846
5000	279 295	168 929	241 957	167 858	180 987	166 808
6000	343 791	207 162	301 796	206 008	223 756	208 346

Abril 1997

Prof. J.Tamashiro

ENTALPIA DE FORMACION DE ALGUNAS SUSTANCIAS (25°C y 1 atm) h_f

SUSTANCIA	FORMULA	M kg/kmol	FASE	$h_f°$ kJ/kmol
Monóxido de Carbono	CO	28	gas	- 110 529
Dióxido de carbono	CO_2	44	gas	- 393 522
Agua	H_2O	18	gas	- 241 827
Agua	H_2O	18	liq	- 285 838
Eteno	C_2H_4	28	gas	+ 52 283
Metano	CH_4	16	gas	- 74873
Etano	C_2H_6	30	gas	- 84 667
Propano	C_3H_8	44	gas	- 103 847
Propano	C_3H_8	44	liq	- 118 515
Butano	C_4H_{10}	58	gas	- 126 148
Butano	C_4H_{10}	58	liq	- 144 509
Pentano	C_5H_{12}	72	gas	- 146 440
Pentano	C_5H_{12}	72	liq	- 170 954
Hexano	C_6H_{14}	86	gas	- 167 197
Hexano	C_6H_{14}	86	liq	- 198 956
Heptano	C_7H_{16}	100	gas	- 187 815
Heptano	C_7H_{16}	100	liq	- 224 538
Octano	C_8H_{18}	114	gas	- 208 447
Octano	C_8H_{18}	114	liq	- 249 952
Benceno	C_6H_6	78	gas	+ 82 936
Benceno	C_6H_6	78	liq	+ 51 058
Acetona	C_3H_6O	58	gas	- 216 834
Acetona	C_3H_6O	58	liq	- 248 360
Metanol	CH_4O	32	gas	- 201 385
Metanol	CH_4O	32	liq	- 238 815
Etanol	C_2H_6O	46	gas	- 235 465
Etanol	C_2H_6O	46	liq	- 277 794
Acido Fórmico	CH_2O_2	46	gas	- 362 867
Acido Acético	$C_2H_4O_2$	60	gas	- 438 441
Alcohol Metílico	CH_3OH	32	gas	- 201 157
Monóxido de Azufre	SO	48	gas	+ 79 632
Bióxido de Azufre	SO_2	64	gas	- 297 095
Trióxido de Azufre	SO_3	80	gas	- 395 192
Sulfuro de Hidrógeno	H_2S	34	gas	- 20 159

ANEXO 4

TABLE 6

CORRELATION OF COMBUSTION WAVE PARAMETERS WITH QUENCHING DISTANCES d (MINIMUM FLAME DIAMETER) BY MEANS OF THE CONCEPT OF CRITICAL FLAME STRETCH, USING $K = 4(v_b/d)(\rho_u/\rho_b)^2$

Fuel[a] Per cent	Stoichiometric fraction[b]	S_u (cm./sec.)	T_b (°K.)	$k \times 10^5$ cal. sec.$^{-1}$/cm. °C.	c_p cal./g. °C.	$\rho_u \times 10^3$ g./cm.^{3}	ρ_u/ρ_b	$v_b \times 10^2$ cm.	d (mm.)	K
					CH_4–O_2					
10	0.22	80	2200	6.3	0.33	1.24	7.3	1.92	0.078	0.7
15	0.35	175	2650	6.4	0.36	1.20	8.8	0.85	0.050	0.6
25	0.67	304	3000	6.5	0.43	1.14	10.0	0.44	0.035	0.5
40	1.47	305	3000	6.7	0.57	1.04	12.7	0.37	0.050	0.4
50	2.00	112	2650	6.9	0.63	0.98	13.3	0.98	0.16	0.3
					C_2H_2–O_2					
7.4	0.4	240	2500	6.1	0.30	1.35	9.0	0.64	0.036	0.6
13.1	0.8	382	3000	5.9	0.32	1.37	11.3	0.35	0.026	0.6
19.3	1.2	320	3000	5.8	0.36	1.41	13.6	0.36	0.029	0.7
21.9	1.4	235	2800	5.7	0.37	1.41	14.3	0.47	0.034	0.8
22.7	1.47	190	2750	5.7	0.37	1.41	14.5	0.68	0.037	0.9
	N_2/O_2			CH_4–O_2–N_2, stoichiometric fraction = 1.1						
35.5	0	326	3050	6.2	0.52	1.07	10.8	0.34	0.040	0.4
26.4	0.5	240	2940	6.3	0.45	1.09	10.2	0.54	0.045	0.5
21.5	1.0	170	2810	6.4	0.41	1.10	9.7	0.83	0.053	0.6
16.1	1.86	110	2620	6.5	0.37	1.11	9.1	1.42	0.079	0.6
10.3	air	42	2200	6.5	0.33	1.12	7.5	4.2	0.25	0.5

					H_2–air					
20	0.60	100	1910	7.2	0.30	0.96	5.7	2.5	0.071	0.8
30	1.01	195	2300	8.0	0.34	0.93	6.5	1.3	0.064	0.5
40	1.58	265	2240	9.0	0.39	0.81	6.5	1.1	0.076	0.4
57	3.15	190	1850	9.0	0.51	0.61	5.5	1.5	0.165	0.2
					CH_4–air					
6.84	0.7	15	1900	6.5	0.30	1.14	6.3	12.5	0.29	1.1
7.76	0.8	27	2000	6.5	0.31	1.14	6.7	6.8	0.22	0.8
8.62	0.9	35	2150	6.5	0.32	1.13	7.2	5.2	0.20	0.8
9.50	1.0	43	2250	6.5	0.32	1.12	7.5	4.2	0.21	0.6
10.3	1.1	42	2200	6.5	0.33	1.12	7.5	4.2	0.25	0.5
11.6	1.25	25	2100	6.5	0.34	1.12	7.5	6.9	0.45	0.5
					C_2H_2–air					
2.86	0.7	28	1870	6.5	0.278	1.18	6.4	7.1	0.42	0.4
3.64	0.9	35	2170	6.5	0.282	1.19	7.5	5.5	0.24	0.7
4.02	1.0	40	2240	6.5	0.286	1.20	7.8	4.8	0.19	0.8
5.08	1.28	27	2120	6.5	0.290	1.20	7.8	6.9	0.17	1.3
5.52	1.40	17	2030	6.5	0.292	1.21	7.5	10.8	0.20	1.6
5.91	1.50	12	1830	6.5	0.294	1.22	6.9	16.4	0.25	1.8

[a] Pressure = 1 atmosphere, $T_u = 300$°K.
[b] Stoichiometric fraction = (% fuel/% O_2)/(% fuel/% $O_{2\ stoich.}$); stoichiometric combustion to CO_2 and H_2O.

ANEXO 5

Las derivadas de las ecuaciones estudiadas para el cálculo de su respectiva incertidumbre son las siguientes:

1- Error absoluto en el caudal de GLP (L/min)

$$Q_{GLP} = \frac{\overline{V}_{GLP}}{t}$$

$$\delta Q_{GLP} = \frac{\delta V_{GLP}}{t}$$

$$\Delta Q_{GLP} = \frac{\Delta V_{GLP}}{t}$$

2- Error absoluto en la densidad de la sustancia (g/L)

$$\rho = \frac{P \times M}{Ru \times T}$$

$$\delta\rho = \frac{\big(\delta(P \times M)\big) * (Ru \times T) - \big(\delta(Ru \times T)\big) * (P \times M)}{(Ru \times T)^2}$$

$$\delta\rho = \frac{(\delta P \times M) * (Ru \times T) - (Ru \times \delta T) * (P \times M)}{(Ru \times T)^2}$$

$$\delta\rho = \frac{(\delta P \times M) * (Ru \times T) - (Ru \times \delta T) * (P \times M)}{(Ru \times T)^2}$$

$$\delta\rho = \left(\frac{(\delta P) * (Ru \times T)}{P(Ru \times T)^2} - \frac{(Ru \times \delta T)}{Ru \times T}\right) * \left(\frac{P \times M}{Ru \times T}\right)$$

$$\delta\rho = \left(\frac{(\delta P) * (Ru \times T)}{P(Ru \times T)} - \frac{(Ru \times \delta T)}{Ru \times T}\right) * \left(\frac{P \times M}{Ru \times T}\right)$$

$$\delta\rho = \left(\frac{\delta P}{P} - \frac{\delta T}{T}\right) * \rho$$

Al tratarse de incertidumbres las restas se deben convertir a sumas debido a que la incertidumbre es un rango entre un valor positivo y negativo. Se reescribe la expresión:

$$\Delta\rho = \left(\frac{\Delta P}{P} + \frac{\Delta T}{T}\right) * \rho$$

3- Error absoluto en el flujo másico de la sustancia (g/s)

$$\dot{m} = Q \times \rho$$

$$\delta\dot{m} = \delta Q \times \rho + Q \times \delta\rho$$

$$\delta\dot{m} = \left(\frac{\delta Q \times \rho + Q \times \delta\rho}{Q \times \rho}\right) * \dot{m}$$

$$\delta\dot{m} = \left(\frac{\delta Q}{Q} + \frac{\delta\rho}{\rho}\right) * \dot{m}$$

$$\Delta\dot{m} = \left(\frac{\Delta Q}{Q} + \frac{\Delta\rho}{\rho}\right) * \dot{m}$$

4- Error absoluto en el flujo másico de la mezcla combustible (g/s)

$$\dot{m}_{mezcla} = \dot{m}_{GLP} + \dot{m}_{aire}$$
$$\delta\dot{m}_{mezcla} = \delta\dot{m}_{GLP} + \delta\dot{m}_{aire}$$
$$\Delta\dot{m}_{mezcla} = \Delta\dot{m}_{GLP} + \Delta\dot{m}_{aire}$$

5- Error absoluto en la densidad de la mezcla combustible (g/L)

$$\rho_{mezcla} = \left[\frac{1}{\rho_{aire}} + \frac{\dot{m}_{GLP}}{\dot{m}_{aire}}\left(\frac{1}{\rho_{GLP}}\right)\right]^{-1}$$

$$\delta\rho_{mezcla} = \frac{\frac{\delta\rho_{aire}}{\rho_{aire}^{2}} - \frac{(\delta\dot{m}_{GLP} * \dot{m}_{aire} * \rho_{GLP}) - (\delta\dot{m}_{aire} * \rho_{GLP} * \dot{m}_{GLP}) - (\delta\rho_{GLP} * \dot{m}_{GLP} * \dot{m}_{aire})}{\dot{m}_{aire}^{2} * \rho_{GLP}^{2}}}{\left[\frac{1}{\rho_{aire}} + \frac{\dot{m}_{GLP}}{\dot{m}_{aire}}\left(\frac{1}{\rho_{GLP}}\right)\right]^{2}}$$

$$\Delta\rho_{mezcla} = \frac{\frac{\Delta\rho_{aire}}{\rho_{aire}^{2}} + \frac{(\Delta\dot{m}_{GLP} * \dot{m}_{aire} * \rho_{GLP}) + (\Delta\dot{m}_{aire} * \rho_{GLP} * \dot{m}_{GLP}) + (\Delta\rho_{GLP} * \dot{m}_{GLP} * \dot{m}_{aire})}{\dot{m}_{aire}^{2} * \rho_{GLP}^{2}}}{\left[\frac{1}{\rho_{aire}} + \frac{\dot{m}_{GLP}}{\dot{m}_{aire}}\left(\frac{1}{\rho_{GLP}}\right)\right]^{2}}$$

6- Error absoluto en el caudal de la mezcla combustible (L/s)

$$Q = \frac{\dot{m}}{\rho}$$

$$\delta Q = \left(\frac{\delta\dot{m} * \rho - \dot{m} * \delta\rho}{\rho^2}\right)$$

$$\delta Q = \left(\frac{\delta\dot{m}}{\dot{m}} - \frac{\delta\rho}{\rho}\right)\frac{\dot{m}}{\rho}$$

$$\delta Q = \left(\frac{\delta\dot{m}}{\dot{m}} - \frac{\delta\rho}{\rho}\right) * Q$$

$$\Delta Q = \left(\frac{\Delta\dot{m}}{\dot{m}} + \frac{\Delta\rho}{\rho}\right) * Q$$

7- Error absoluto en el área que forma la llama (cm^2)

$$A_{llama} = \frac{\pi \times d^2}{4}$$

$$\delta A_{llama} = \frac{\pi * d * \delta d}{2}$$

$$\Delta A_{llama} = \frac{\pi * d * \Delta d}{2}$$

8- Error absoluto en la velocidad de la llama laminar de la mezcla (cm/s)

$$S_L = \frac{1000 \times Q_{mezcla}}{A_{llama}}$$

$$\delta S_L = \left(\frac{\delta Q_{mezcla}}{Q_{mezcla}} - \frac{\delta A_{llama}}{A_{llama}}\right) * S_L$$

$$\Delta S_L = \left(\frac{\Delta Q_{mezcla}}{Q_{mezcla}} + \frac{\Delta A_{llama}}{A_{llama}}\right) * S_L$$

9- Error en la relación de aire-combustible de la mezcla (kg aire/ kg comb)

$$r_{a/c} = \frac{\dot{m}_{aire}}{\dot{m}_{GLP}}$$

$$\delta r_{a/c} = \left(\frac{\delta \dot{m}_{aire}}{\dot{m}_{aire}} - \frac{\delta \dot{m}_{GLP}}{\dot{m}_{GLP}}\right) * r_{a/c}$$

$$\Delta r_{a/c} = \left(\frac{\Delta \dot{m}_{aire}}{\dot{m}_{aire}} + \frac{\Delta \dot{m}_{GLP}}{\dot{m}_{GLP}}\right) * r_{a/c}$$

10- Error en la fracción estequiométrica

$$\Phi = \frac{r_{a/c_{Ideal}}}{r_{a/c}}$$

$$\delta\Phi = \frac{0 * r_{a/c_{Ideal}} - r_{a/c_{Ideal}} * \delta r_{a/c}}{{r_{a/c}}^2}$$

$$\delta\Phi = \frac{-\delta r_{a/c}}{r_{a/c}} * \Phi$$

$$\Delta\Phi = \frac{\Delta r_{a/c}}{r_{a/c}} * \Phi$$