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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% ESTUDO DA CONVERGÊNCIA DE SOLUÇÕES  $\mu$  PARA A EQUAÇÃO TRANSCENDENTAL
%  $\mu * \cot(\mu) + Bi = 0$ , com diferentes valores do número de Biot
%
% Objetivo: Verificar numericamente a convergência das raízes  $\mu_i$ 
% para diferentes regimes térmicos ( $Bi$  pequeno  $\rightarrow$  resistência externa alta;
%  $Bi$  grande  $\rightarrow$  condução dominante).
%
% Valores considerados de  $Bi$ : 0.1, 1.67, 5, 50
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clear;
close all;

% Parâmetros do problema
Bi_values = [0.1, 1.67, 5, 50]; % Números de Biot a serem analisados
N = 100; % Número de raízes a calcular
epsilon = 1e-6; % Tolerância para o resíduo |f(mu_i)|

% Para armazenar os resultados de cada Bi
Tabelas = cell(length(Bi_values), 1);

% Loop sobre cada valor de Bi
for b = 1:length(Bi_values)
    Bi = Bi_values(b); % Valor atual de Bi
    f = @(mu) mu .* cot(mu) + Bi; % Função transcendental

    mu = zeros(1, N); % Vetor para armazenar as raízes
    residual = zeros(1, N); % Resíduos |f(mu_i)|
    status = strings(1, N); % Status "OK" ou "Fora"

    % Loop para calcular as N primeiras raízes positivas
    for i = 1:N
        a = (i - 1) * pi + 0.001; % Limite inferior do intervalo
        b_val = i * pi - 0.001; % Limite superior do intervalo

        mu(i) = fzero(f, [a, b_val]); % Cálculo da raiz no intervalo

        residual(i) = abs(f(mu(i))); % Cálculo do resíduo

        % Classificação da raiz de acordo com a tolerância
        if residual(i) < epsilon
            status(i) = "OK";
        else
            status(i) = "Fora";
        end
    end
end

% Criar e armazenar a tabela de resultados

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```

T = table((1:N)', mu', residual', status', ...
          'VariableNames', {'i', 'mu_i', 'f_mu_i', 'Status'});

Tabelas{b} = T;

% Exibir no console com cabeçalho
fprintf('\n===== Tabela para Bi = %.2f =====\n', Bi);
disp(T)
end

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===== Tabela para Bi = 0.10 =====

```

i	mu_i	f_mu_i	Status
1	1.632	1.5266e-16	"OK"
2	4.7335	7.7716e-16	"OK"
3	7.8667	4.1633e-17	"OK"
4	11.005	9.6173e-15	"OK"
5	14.144	6.1062e-15	"OK"
6	17.285	1.0963e-15	"OK"
7	20.425	3.6193e-14	"OK"
8	23.566	1.8041e-15	"OK"
9	26.707	3.2571e-14	"OK"
10	29.848	1.9718e-13	"OK"
11	32.99	1.2618e-13	"OK"
12	36.131	7.129e-14	"OK"
13	39.272	6.703e-15	"OK"
14	42.414	1.4284e-13	"OK"
15	45.555	4.4145e-14	"OK"
16	48.697	2.391e-13	"OK"
17	51.838	1.42e-13	"OK"
18	54.98	7.111e-14	"OK"
19	58.121	1.6538e-13	"OK"
20	61.263	1.0456e-13	"OK"
21	64.404	1.3045e-15	"OK"
22	67.546	2.0099e-13	"OK"
23	70.687	4.6782e-14	"OK"
24	73.829	4.1178e-13	"OK"
25	76.97	1.3457e-13	"OK"
26	80.112	3.2245e-13	"OK"
27	83.253	2.2998e-13	"OK"
28	86.395	6.0146e-13	"OK"
29	89.537	5.4366e-13	"OK"
30	92.678	6.5656e-13	"OK"
31	95.82	3.1687e-13	"OK"
32	98.961	4.3031e-13	"OK"
33	102.1	6.4412e-13	"OK"
34	105.24	5.9386e-13	"OK"
35	108.39	9.0178e-14	"OK"
36	111.53	2.3874e-13	"OK"
37	114.67	2.2461e-13	"OK"
38	117.81	6.4308e-13	"OK"
39	120.95	1.516e-13	"OK"
40	124.09	4.8092e-13	"OK"
41	127.24	8.6139e-13	"OK"
42	130.38	5.4964e-13	"OK"
43	133.52	6.844e-13	"OK"
44	136.66	1.1006e-12	"OK"
45	139.8	1.7328e-12	"OK"
46	142.94	1.4782e-12	"OK"
47	146.08	1.3471e-12	"OK"
48	149.23	2.0424e-13	"OK"

49	152.37	1.1597e-12	"OK"
50	155.51	9.2133e-13	"OK"
51	158.65	1.2952e-12	"OK"
52	161.79	1.2324e-12	"OK"
53	164.93	1.1702e-12	"OK"
54	168.08	9.7736e-13	"OK"
55	171.22	1.1844e-12	"OK"
56	174.36	2.6869e-13	"OK"
57	177.5	1.3408e-12	"OK"
58	180.64	2.5621e-13	"OK"
59	183.78	2.1603e-12	"OK"
60	186.93	7.6318e-13	"OK"
61	190.07	1.1036e-12	"OK"
62	193.21	2.3534e-12	"OK"
63	196.35	2.0289e-12	"OK"
64	199.49	1.1422e-12	"OK"
65	202.63	2.6464e-12	"OK"
66	205.77	2.7534e-12	"OK"
67	208.92	2.4953e-12	"OK"
68	212.06	2.5275e-12	"OK"
69	215.2	8.3593e-13	"OK"
70	218.34	1.542e-12	"OK"
71	221.48	2.5434e-12	"OK"
72	224.62	5.1251e-14	"OK"
73	227.77	3.6839e-13	"OK"
74	230.91	1.4898e-12	"OK"
75	234.05	2.6704e-12	"OK"
76	237.19	1.1391e-12	"OK"
77	240.33	8.7891e-13	"OK"
78	243.47	4.144e-12	"OK"
79	246.62	5.8045e-12	"OK"
80	249.76	1.1712e-12	"OK"
81	252.9	1.4349e-11	"OK"
82	256.04	2.9056e-12	"OK"
83	259.18	1.2282e-14	"OK"
84	262.32	6.6926e-12	"OK"
85	265.46	7.3919e-12	"OK"
86	268.61	3.5744e-12	"OK"
87	271.75	7.6187e-12	"OK"
88	274.89	5.463e-12	"OK"
89	278.03	8.0516e-13	"OK"
90	281.17	2.2836e-12	"OK"
91	284.31	5.3636e-12	"OK"
92	287.46	5.5201e-12	"OK"
93	290.6	3.7755e-12	"OK"
94	293.74	6.8722e-12	"OK"
95	296.88	3.8468e-13	"OK"
96	300.02	7.6632e-12	"OK"
97	303.16	6.7194e-12	"OK"
98	306.31	1.3184e-15	"OK"
99	309.45	1.4951e-13	"OK"
100	312.59	7.9577e-13	"OK"

===== Tabela para Bi = 1.67 =====

i	mu_i	f_mu_i	Status
1	2.2165	2.2204e-16	"OK"
2	5.0328	1.7764e-15	"OK"
3	8.0583	6.4393e-15	"OK"
4	11.144	1.3323e-15	"OK"
5	14.254	4.6629e-15	"OK"
6	17.375	5.7732e-15	"OK"
7	20.502	8.2157e-15	"OK"
8	23.632	8.149e-14	"OK"

9	26.766	4.2411e-14	"OK"
10	29.901	4.019e-14	"OK"
11	33.037	8.8596e-14	"OK"
12	36.174	1.5099e-14	"OK"
13	39.312	5.7732e-14	"OK"
14	42.451	9.0816e-14	"OK"
15	45.59	9.6811e-14	"OK"
16	48.729	1.3767e-13	"OK"
17	51.868	1.3878e-13	"OK"
18	55.008	3.8836e-13	"OK"
19	58.148	3.9013e-13	"OK"
20	61.288	4.8295e-13	"OK"
21	64.429	6.9011e-13	"OK"
22	67.569	4.0168e-13	"OK"
23	70.709	1.1902e-13	"OK"
24	73.85	1.9007e-13	"OK"
25	76.991	2.4558e-13	"OK"
26	80.131	2.3981e-14	"OK"
27	83.272	1.4877e-14	"OK"
28	86.413	6.0241e-13	"OK"
29	89.554	2.9154e-13	"OK"
30	92.695	3.3329e-13	"OK"
31	95.836	5.7465e-13	"OK"
32	98.977	5.1337e-13	"OK"
33	102.12	1.0369e-13	"OK"
34	105.26	7.0943e-13	"OK"
35	108.4	5.0737e-13	"OK"
36	111.54	2.669e-13	"OK"
37	114.68	3.8258e-13	"OK"
38	117.82	2.5357e-13	"OK"
39	120.97	5.147e-13	"OK"
40	124.11	2.2982e-13	"OK"
41	127.25	1.4522e-13	"OK"
42	130.39	1.4326e-12	"OK"
43	133.53	1.7089e-12	"OK"
44	136.67	1.9298e-12	"OK"
45	139.81	1.8892e-12	"OK"
46	142.95	1.7719e-13	"OK"
47	146.1	1.9149e-12	"OK"
48	149.24	8.9129e-13	"OK"
49	152.38	7.1387e-13	"OK"
50	155.52	6.859e-13	"OK"
51	158.66	7.9403e-13	"OK"
52	161.8	1.6622e-12	"OK"
53	164.94	1.9955e-12	"OK"
54	168.09	8.9151e-13	"OK"
55	171.23	9.9809e-13	"OK"
56	174.37	2.3554e-12	"OK"
57	177.51	1.6169e-12	"OK"
58	180.65	1.9087e-12	"OK"
59	183.79	2.3803e-12	"OK"
60	186.93	1.1042e-12	"OK"
61	190.08	2.0228e-12	"OK"
62	193.22	1.5272e-12	"OK"
63	196.36	5.5822e-13	"OK"
64	199.5	1.6505e-12	"OK"
65	202.64	4.4409e-16	"OK"
66	205.78	1.884e-12	"OK"
67	208.92	2.0028e-13	"OK"
68	212.07	2.109e-12	"OK"
69	215.21	1.8319e-13	"OK"
70	218.35	2.1341e-12	"OK"
71	221.49	1.3887e-12	"OK"
72	224.63	2.4614e-12	"OK"

73	227.77	1.8585e-12	"OK"
74	230.91	1.2548e-12	"OK"
75	234.06	2.1168e-12	"OK"
76	237.2	3.4572e-13	"OK"
77	240.34	5.0404e-14	"OK"
78	243.48	2.0783e-12	"OK"
79	246.62	2.6925e-12	"OK"
80	249.76	6.0307e-13	"OK"
81	252.9	3.3706e-13	"OK"
82	256.05	2.3019e-12	"OK"
83	259.19	5.1641e-12	"OK"
84	262.33	2.8391e-12	"OK"
85	265.47	9.7189e-13	"OK"
86	268.61	5.0593e-12	"OK"
87	271.75	1.7766e-12	"OK"
88	274.9	6.7799e-12	"OK"
89	278.04	7.049e-12	"OK"
90	281.18	4.6718e-12	"OK"
91	284.32	5.2236e-12	"OK"
92	287.46	1.1378e-12	"OK"
93	290.6	7.1536e-12	"OK"
94	293.74	6.1557e-12	"OK"
95	296.89	6.406e-13	"OK"
96	300.03	5.2827e-12	"OK"
97	303.17	5.9723e-12	"OK"
98	306.31	4.7184e-13	"OK"
99	309.45	1.7297e-13	"OK"
100	312.59	3.717e-13	"OK"

===== Tabela para Bi = 5.00 =====

i	mu_i	f_mu_i	Status
1	2.6537	1.7764e-15	"OK"
2	5.4544	1.0658e-14	"OK"
3	8.3913	5.3291e-15	"OK"
4	11.409	1.1546e-14	"OK"
5	14.47	9.77e-15	"OK"
6	17.556	1.7764e-15	"OK"
7	20.658	2.5757e-14	"OK"
8	23.769	2.4869e-14	"OK"
9	26.887	1.1902e-13	"OK"
10	30.01	4.7962e-14	"OK"
11	33.136	1.1546e-14	"OK"
12	36.265	1.1458e-13	"OK"
13	39.396	5.1514e-14	"OK"
14	42.529	1.199e-13	"OK"
15	45.662	6.1284e-14	"OK"
16	48.797	7.0166e-14	"OK"
17	51.932	1.4744e-13	"OK"
18	55.068	1.1724e-13	"OK"
19	58.205	3.8192e-14	"OK"
20	61.342	8.793e-14	"OK"
21	64.48	9.5923e-14	"OK"
22	67.618	3.0997e-13	"OK"
23	70.756	2.2116e-13	"OK"
24	73.895	7.1942e-14	"OK"
25	77.034	7.4607e-14	"OK"
26	80.173	3.9968e-14	"OK"
27	83.312	1.954e-14	"OK"
28	86.452	4.5031e-13	"OK"
29	89.591	4.5919e-13	"OK"
30	92.731	5.1603e-13	"OK"
31	95.871	2.7889e-13	"OK"
32	99.011	2.2116e-13	"OK"

33	102.15	9.2371e-14	"OK"
34	105.29	3.2863e-14	"OK"
35	108.43	7.5584e-13	"OK"
36	111.57	2.0606e-13	"OK"
37	114.71	3.3129e-13	"OK"
38	117.85	3.1353e-13	"OK"
39	120.99	3.0731e-13	"OK"
40	124.13	1.1458e-13	"OK"
41	127.27	6.8212e-13	"OK"
42	130.41	3.3245e-12	"OK"
43	133.56	3.6167e-12	"OK"
44	136.7	2.9896e-12	"OK"
45	139.84	1.3207e-12	"OK"
46	142.98	4.0208e-12	"OK"
47	146.12	1.0845e-12	"OK"
48	149.26	2.6086e-12	"OK"
49	152.4	2.9274e-12	"OK"
50	155.54	1.0258e-12	"OK"
51	158.68	1.0232e-12	"OK"
52	161.82	1.8421e-12	"OK"
53	164.96	2.5748e-12	"OK"
54	168.1	2.1219e-12	"OK"
55	171.25	1.7737e-12	"OK"
56	174.39	2.3368e-12	"OK"
57	177.53	1.2257e-12	"OK"
58	180.67	1.628e-12	"OK"
59	183.81	1.1164e-12	"OK"
60	186.95	3.7925e-13	"OK"
61	190.09	3.4106e-13	"OK"
62	193.23	3.2419e-13	"OK"
63	196.37	2.5677e-12	"OK"
64	199.52	2.2276e-12	"OK"
65	202.66	7.1942e-14	"OK"
66	205.8	1.7408e-12	"OK"
67	208.94	4.6807e-13	"OK"
68	212.08	1.0818e-12	"OK"
69	215.22	1.6502e-12	"OK"
70	218.36	2.0997e-12	"OK"
71	221.5	3.0855e-12	"OK"
72	224.65	1.5046e-12	"OK"
73	227.79	2.0277e-12	"OK"
74	230.93	9.7344e-13	"OK"
75	234.07	1.5685e-12	"OK"
76	237.21	2.1663e-12	"OK"
77	240.35	9.7877e-13	"OK"
78	243.49	1.5934e-12	"OK"
79	246.64	2.0499e-12	"OK"
80	249.78	2.2284e-12	"OK"
81	252.92	3.2152e-12	"OK"
82	256.06	8.4555e-13	"OK"
83	259.2	4.6709e-12	"OK"
84	262.34	1.0045e-12	"OK"
85	265.48	2.4567e-12	"OK"
86	268.62	6.9065e-12	"OK"
87	271.77	1.7524e-12	"OK"
88	274.91	4.2117e-12	"OK"
89	278.05	2.883e-12	"OK"
90	281.19	6.5814e-13	"OK"
91	284.33	7.9963e-12	"OK"
92	287.47	1.5365e-12	"OK"
93	290.61	6.3149e-12	"OK"
94	293.76	4.7411e-12	"OK"
95	296.9	1.1209e-12	"OK"
96	300.04	5.7838e-12	"OK"

97	303.18	4.8139e-12	"OK"
98	306.32	3.8627e-12	"OK"
99	309.46	8.5603e-12	"OK"
100	312.6	1.3696e-12	"OK"
===== Tabela para Bi = 50.00 =====			
i	mu_i	f_mu_i	Status
1	3.0801	3.5527e-14	"OK"
2	6.1606	1.8474e-13	"OK"
3	9.242	1.9895e-13	"OK"
4	12.325	5.6843e-14	"OK"
5	15.409	2.7711e-13	"OK"
6	18.495	1.2079e-13	"OK"
7	21.584	9.2371e-14	"OK"
8	24.674	5.6843e-14	"OK"
9	27.767	2.8422e-14	"OK"
10	30.863	9.9476e-14	"OK"
11	33.961	3.6948e-13	"OK"
12	37.061	3.4817e-13	"OK"
13	40.164	1.6342e-13	"OK"
14	43.269	2.1316e-13	"OK"
15	46.376	1.4921e-13	"OK"
16	49.485	3.4106e-13	"OK"
17	52.596	2.9843e-13	"OK"
18	55.709	1.0658e-13	"OK"
19	58.824	2.1316e-14	"OK"
20	61.94	2.7711e-13	"OK"
21	65.058	1.0658e-13	"OK"
22	68.177	0	"OK"
23	71.297	1.8474e-13	"OK"
24	74.419	5.3291e-13	"OK"
25	77.542	4.9738e-13	"OK"
26	80.665	7.2475e-13	"OK"
27	83.79	5.5422e-13	"OK"
28	86.916	1.279e-13	"OK"
29	90.042	8.1002e-13	"OK"
30	93.17	1.279e-13	"OK"
31	96.297	1.7053e-13	"OK"
32	99.426	1.279e-13	"OK"
33	102.56	7.0344e-13	"OK"
34	105.69	2.4158e-13	"OK"
35	108.82	7.1054e-15	"OK"
36	111.95	3.4817e-13	"OK"
37	115.08	1.6342e-13	"OK"
38	118.21	3.1264e-13	"OK"
39	121.34	3.1264e-13	"OK"
40	124.47	6.0396e-13	"OK"
41	127.61	5.7554e-13	"OK"
42	130.74	1.4424e-12	"OK"
43	133.88	3.7659e-13	"OK"
44	137.01	1.5277e-12	"OK"
45	140.14	9.9476e-14	"OK"
46	143.28	2.2169e-12	"OK"
47	146.41	1.1724e-12	"OK"
48	149.55	1.755e-12	"OK"
49	152.68	1.1227e-12	"OK"
50	155.82	1.8687e-12	"OK"
51	158.96	1.5632e-13	"OK"
52	162.09	4.6896e-13	"OK"
53	165.23	9.0949e-13	"OK"
54	168.36	2.3093e-12	"OK"
55	171.5	1.6982e-12	"OK"
56	174.64	2.1032e-12	"OK"

57	177.77	1.6911e-12	"OK"
58	180.91	4.9738e-14	"OK"
59	184.05	4.6896e-13	"OK"
60	187.19	6.537e-13	"OK"
61	190.32	2.5153e-12	"OK"
62	193.46	2.8422e-12	"OK"
63	196.6	1.35e-13	"OK"
64	199.74	1.1653e-12	"OK"
65	202.87	2.629e-13	"OK"
66	206.01	6.267e-12	"OK"
67	209.15	8.9244e-12	"OK"
68	212.29	5.933e-12	"OK"
69	215.43	7.1765e-12	"OK"
70	218.57	4.8175e-12	"OK"
71	221.7	5.933e-12	"OK"
72	224.84	5.8975e-13	"OK"
73	227.98	1.4566e-12	"OK"
74	231.12	4.5048e-12	"OK"
75	234.26	3.2472e-12	"OK"
76	237.4	2.1103e-12	"OK"
77	240.54	3.8369e-13	"OK"
78	243.68	2.6361e-12	"OK"
79	246.81	2.5935e-12	"OK"
80	249.95	3.098e-12	"OK"
81	253.09	3.0553e-13	"OK"
82	256.23	2.2879e-12	"OK"
83	259.37	6.9988e-12	"OK"
84	262.51	2.224e-12	"OK"
85	265.65	2.3093e-12	"OK"
86	268.79	3.4888e-12	"OK"
87	271.93	7.5175e-12	"OK"
88	275.07	2.4656e-12	"OK"
89	278.21	4.1354e-12	"OK"
90	281.35	7.3825e-12	"OK"
91	284.49	3.4674e-12	"OK"
92	287.63	5.6559e-12	"OK"
93	290.77	3.0838e-12	"OK"
94	293.91	7.2902e-12	"OK"
95	297.05	5.0591e-12	"OK"
96	300.19	3.1051e-12	"OK"
97	303.33	5.5564e-12	"OK"
98	306.47	6.3025e-12	"OK"
99	309.61	4.8317e-13	"OK"
100	312.75	1.5632e-13	"OK"