第17回OpenFOAM勉強会@関西
2012.10.13

Conjugate heat transfer problem solved by chtMultiRegion

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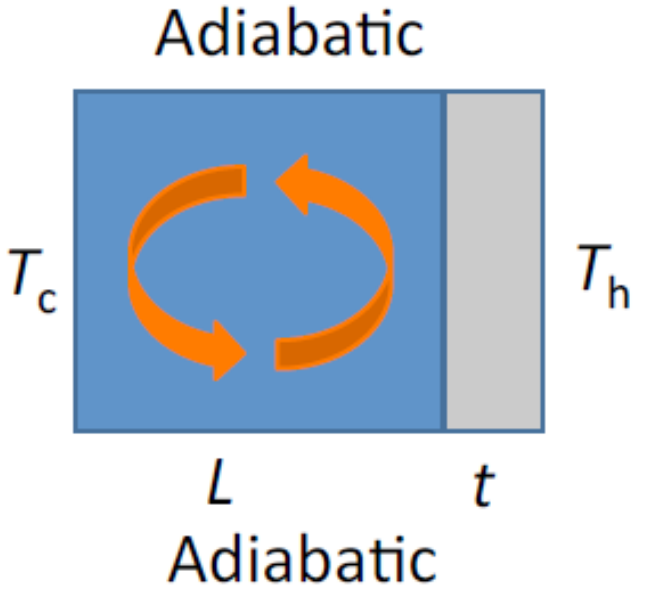
春の宿題

1. 概要

Conjugate heat transfer problem

Kaminski & Prakash, Int. J. Heat Mass Transfer (1986)



Condition

Pr = 0.7 (air)

Gr = 10^3, 10^5, 10^6, 5x10^6, 10^7

t/L = 0.2, 0.4

$(k_w L)/(k_l t)$ = 5, 25, 50, ∞

N_x x N_y = 40 x 30

Results

Stream line, Isotherm

Temp. on solid-liquid interface

Local heat flux

Nusselt number

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2. 気体の物性

Physical propeties of air

	Property	Value
T_C	Temperature [K]	273.
ρ	Density [kg/m3]	1.205
μ	viscosity [Pa·s]	1.7×10^{-5}
c_p	Specific heat [J/(kg·K)]	1.00×10^{3}
k_l	Thermal conductivity [W/(m·K)]	0.0241
β	Thermal expansion coef. [1/K]	3.00×10^{-3}

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3. 諸元

- プラントル数
  - ✓ 動粘度と温度拡散率の比

$$\mathrm{Pr} = \mu c_p / k_l$$

k_l が決定

- グラスホフ数
  - ✓ 浮力と粘性力の比

$$Gr = g\beta(T_H - T_C)L^3/\nu^2$$

具体的な L を与えれば T_H が決まる

- その他
  - ✓ $k_w L/k_l t$ より条件ごとに k_w が決まる
  - ✓ t / L より条件ごとに t が決まる

Condition

Pr = 0.7 (air)

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T_C	Temperature [K]
ρ	Density [kg/m3]
μ	viscosity [Pa·s]
c_p	Specific heat [J/(kg·K)]
β	Thermal expansion coef. [1/K]

基礎方程式(chtMultiRegionFoam)

1. 流体領域
   - Navier-Stokes方程式

$$\frac{\partial}{\partial t}(\rho \mathbf{U}) + \nabla(\boldsymbol{\varphi}\mathbf{U}) = -\nabla p + g\nabla\rho$$

   - エネルギー方程式

$$\frac{\partial}{\partial t}(\rho h) + \nabla(\boldsymbol{\varphi} h) - \alpha\nabla^2 h = \frac{\partial p}{\partial t} - \frac{\partial}{\partial t}(\rho k_l) - \nabla(\boldsymbol{\varphi} k_l)$$

   - 連続の式

$$\frac{\partial}{\partial t}\rho + \nabla(\rho\mathbf{U}) = 0$$

   - 状態方程式

$$\rho = \frac{p}{RT/w}$$

2. 固体領域
   - 拡散方程式

$$\frac{\partial}{\partial t}(\rho c_p T) - k_w \nabla^2 T = 0$$

今回は定常計算。
(chtMultiRegionSimpleFoam)

なお、
g：重力加速度
h：エンタルピ
R：気体定数
w：分子量

解析結果

1. 結果概要
   - 一部解析をし忘れた(Gr=5x10e6)
   - 一部解析が収束しなかった

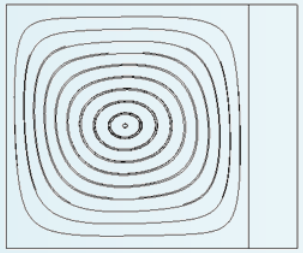
t/L=0.2		Gr				
		10e3	10e5	10e6	5x10e6	10e7
k_wL/k_lt	5	○	○	-	○	○
	25	○	○	-	×	×
	50	○	○	-	×	×
	∞	○	○	-	×	×

t/L=0.4		Gr				
		10e3	10e5	10e6	5x10e6	10e7
k_wL/k_lt	5	○	○	-	○	○
	25	○	○	-	×	×
	50	○	○	-	×	×
	∞	○	○	-	×	×

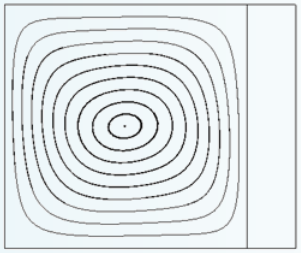
解析結果

2. Stream Line (t/L = 0.2)

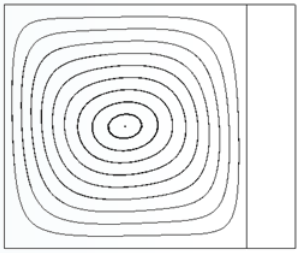
- Gr=10e3



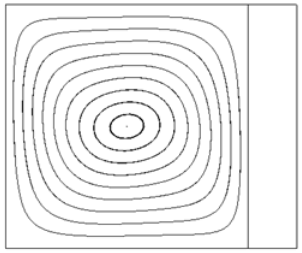
$k_w L/k_l t = 5$



$k_w L/k_l t = 25$

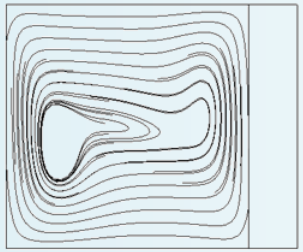


$k_w L/k_l t = 50$

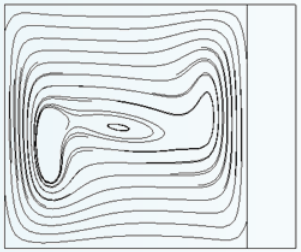


$k_w L/k_l t = \infty$

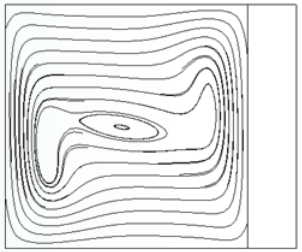
- Gr=10e5



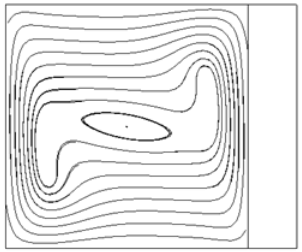
$k_w L/k_l t = 5$



$k_w L/k_l t = 25$



$k_w L/k_l t = 50$

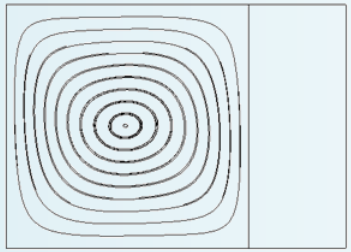


$k_w L/k_l t = \infty$

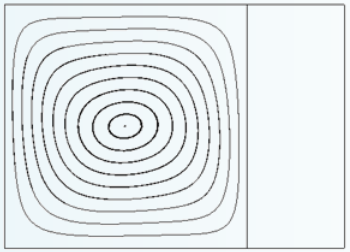
解析結果

3. Stream Line (t/L = 0.4)

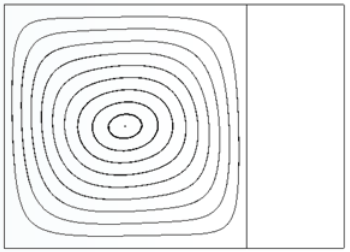
- Gr=10e3



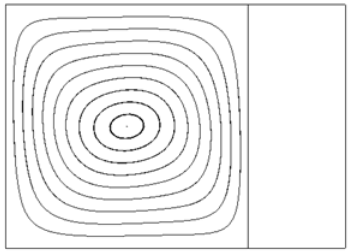
$k_w L/k_l t = 5$



$k_w L/k_l t = 25$

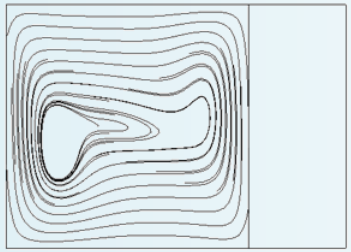


$k_w L/k_l t = 50$

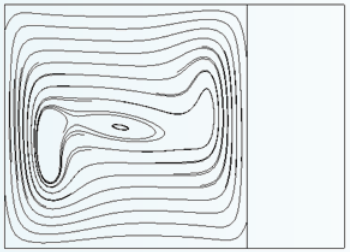


$k_w L/k_l t = \infty$

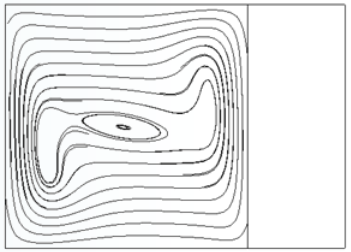
- Gr=10e5



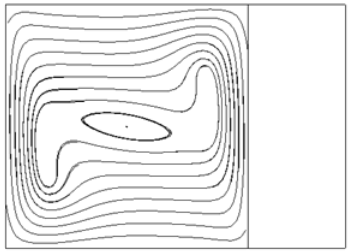
$k_w L/k_l t = 5$



$k_w L/k_l t = 25$



$k_w L/k_l t = 50$

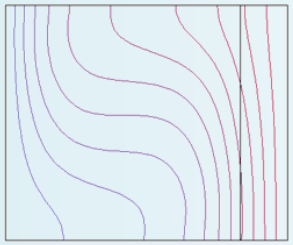
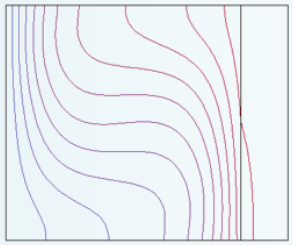
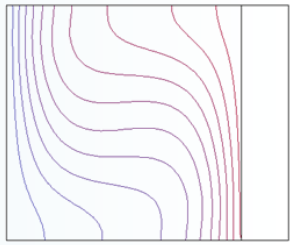
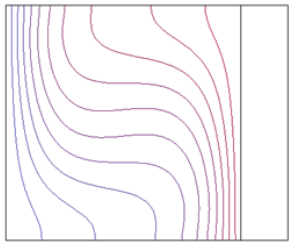
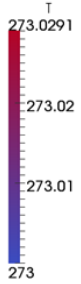


$k_w L/k_l t = \infty$

解析結果

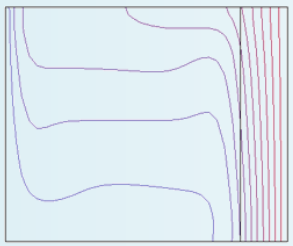
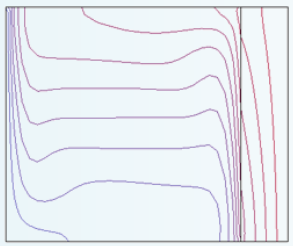
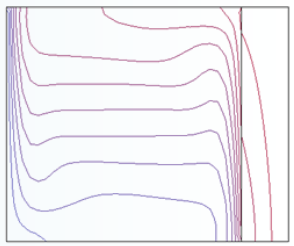
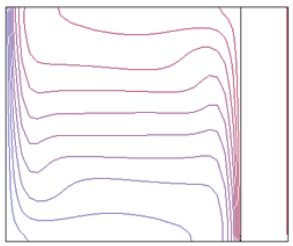
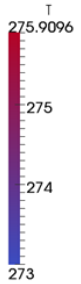
4. isoThermo (t/L = 0.2)

- Gr=10e3

$k_w L/k_l t = 5$　$k_w L/k_l t = 25$　$k_w L/k_l t = 50$　$k_w L/k_l t = \infty$

- Gr=10e5

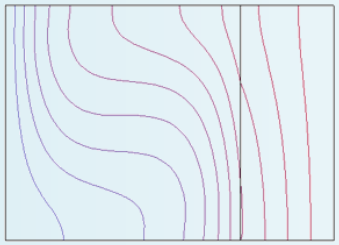
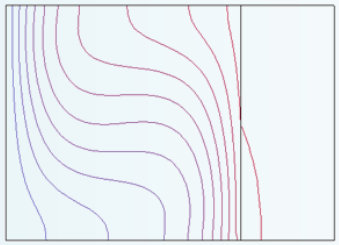
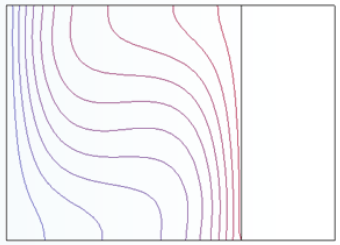
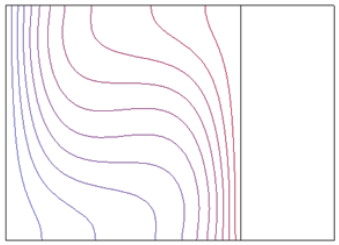
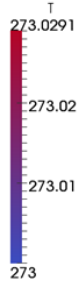






$k_w L/k_l t = 5$　$k_w L/k_l t = 25$　$k_w L/k_l t = 50$　$k_w L/k_l t = \infty$

解析結果

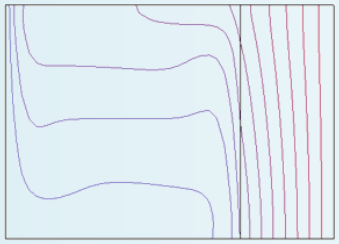
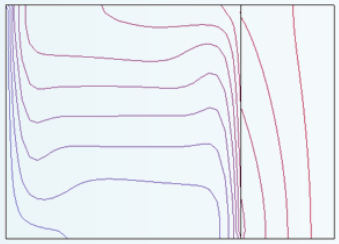
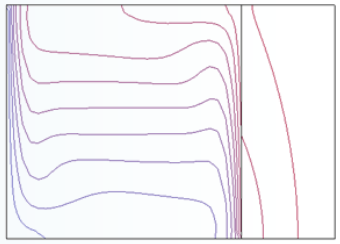
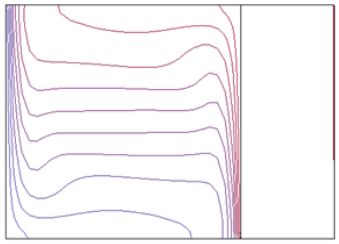
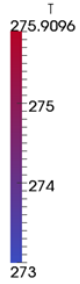
5. isoThermo (t/L = 0.4)

- Gr=10e3

$k_w L/k_l t = 5$　$k_w L/k_l t = 25$　$k_w L/k_l t = 50$　$k_w L/k_l t = \infty$

- Gr=10e5

$k_w L/k_l t = 5$　$k_w L/k_l t = 25$　$k_w L/k_l t = 50$　$k_w L/k_l t = \infty$

解析結果

6. Nusselt number

Gr	$k_w L/k_l t$	$L/t=0.2$	$L/t=0.4$	KAMINSKIら $L/t=0.2$	KAMINSKIら $L/t=0.4$
10e3	5	1.53	1.52	0.87	0.87
	25	2.17	2.17	1.02	1.02
	50	2.30	2.29	1.04	1.04
	∞	2.43	2.43	1.06	1.06
10e5	5	3.11	3.10	2.08	2.08
	25	7.13	7.11	3.42	3.41
	50	8.58	8.55	3.72	3.71
	∞	10.74	10.74	4.08	4.08

まとめ

- 残問題
  - Grが大きいと収束しない
    - 初期場を良くする？
    - 非定常？
    - メッシュ解像度？
    - そもそもなぜ収束しない？
  - Nusselt数が合わない
    - メッシュが温度境界層を表現できていない？
    - 計算方法が違う？
- 参考

Nusselt 数の定義

熱伝達による熱量と熱伝導による熱量の比

今回は以下のように定義

$$Nu = \frac{Q}{k_l\left(T_H - T_C\right)}$$

OpenFOAMでは、wallHeatFluxユーティリティにて
solid-air間を横切る熱量を奥行き(2次元のため)で
除して算出している