

SIMULAÇÃO NUMÉRICA DE ALETAS EM UM CONTEXTO DE ALTAS TEMPERATURAS

R. Sobral

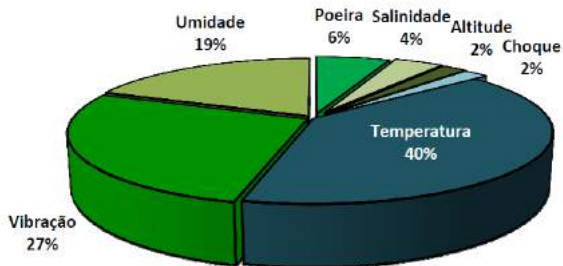
Doutorando em Engenharia Mecânica

rodolfo.sobral@cefet-rj.br

Fundamentos

Muitos dispositivos e equipamentos tem a necessidade de dissipar calor, seja como atividade-fim, otimização de eficiência ou garantia de integridade de sistemas.

Motivação



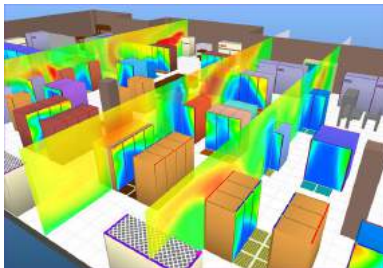
Dispositivos Eletrônicos

Fonte: RAMOS, R. A. V. Análise da convecção natural em superfícies com fontes de calor protuberantes. Doutorado em Engenharia Mecânica - Universidade Estadual de Campinas, São Paulo, 1998.

Grandezas Associadas

- Dispositivos Termoelétricos;
- Efeito Thomson;
- Lei de Curie-Weiss;
- Painéis Fotovoltaicos.

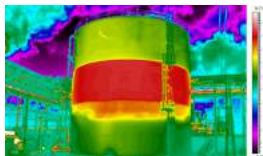
Análise Multifísica



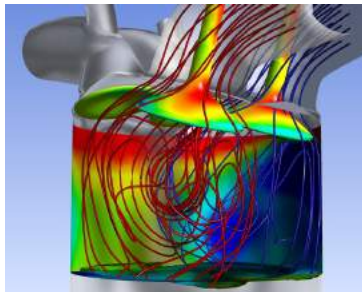
Análise Multifísica



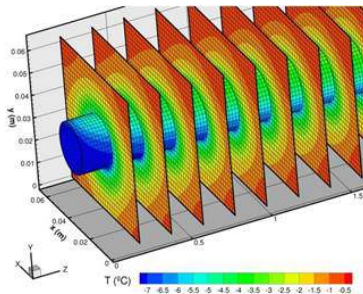
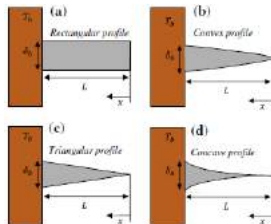
Utility Flares / Vapor Combustion Unit / Fixed Orifice Sonic Flares
by Flare Industries - An Aereon Company



Análise Multifísica



Análise Multifísica



Soluções Analíticas

- Teorema de Duhamel;
- Funções de Green;
- Transformada de Laplace.

Fonte: OZISIK, M. Necati. Heat conduction. John Wiley & Sons, 1993.

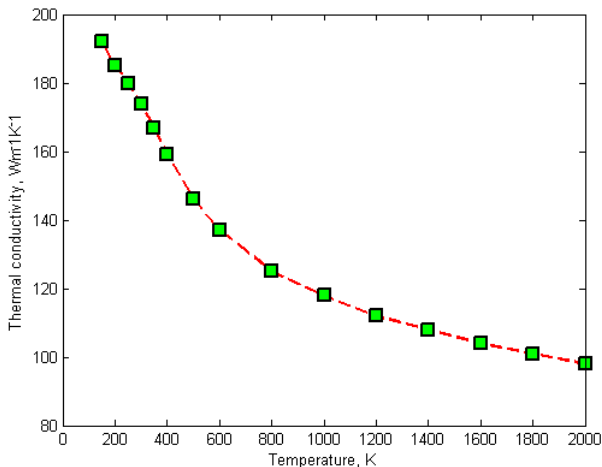
Justificativa

Muitos problemas de transferência de calor não linear não possuem soluções analíticas, além do que softwares de análise multifísica realizam aproximações que podem acarretar a erros consideráveis nos perfis de temperatura.

Ciência dos Materiais

Em ciência dos materiais muitas equações constitutivas são obtidas assumindo condutividade térmica constante, entretanto tal aproximação pode acarretar a erros consideráveis.

Condutividade Térmica do Cobre



Fonte: HO, Cho Yen; POWELL, Reginald W.; LILEY, Peter E. Thermal conductivity of the elements. Journal of Physical and Chemical Reference Data, v. 1, n. 2, p. 279-421, 1972.

Objetivos

- **Principal**

Simulação numérica de processos de transferência de calor em aletas com condutividade térmica variável utilizando-se formulação variacional e construção sequencial de soluções através da Transformada de Kirchhoff.

- **Secundários**

Resolver o problema não linear através do limite da sequência cujos elementos são oriundos da solução de problemas lineares e suas soluções são obtidas por meio da minimização de funcionais quadráticos.

Estudos Recentes

International Journal of Thermal Sciences 67 (2012) 137–147



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An assessment on air forced convection on extended surfaces: Experimental results and numerical modeling

Andrea Diani, Simone Mancini*, Claudio Zilio, Luisa Rossetto

Dipartimento di Ingegneria Industriale, Università di Padova, Via Venezia 1, 35130, 35130, Italy; rossetto@unipadova.it

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ABSTRACT

An air flow and pin fin, widely used in electronic, aerospace and air conditioning applications, thermal and pin fin heat transfer properties, it usually flows through extended surfaces, such as finned surfaces, to enhance the convective heat transfer. In this paper, experimental results are reviewed, and numerical studies during turbulent air forced convection through extended surfaces are presented. The thermal and hydraulic behavior of a rectangular extended finned surface, experimentally studied by previous authors in an open-circuit wind tunnel, has been compared with numerical simulations carried out by using the commercial CFD software **ANSYS FLUENT**. The model has been validated, numerical simulations have been run under different configurations, in order to study the effects of the fin thickness, the pin fin height on the thermohydraulic behavior of the extended surfaces. Moreover, several pin fin surfaces have been simulated in the same range of operating conditions previously analyzed. Numerical results about heat transfer and pressure drop both for pin finned surfaces and for pin fin surfaces, have been compared with empirical correlations from the open literature, and more accurate equations have been developed and proposed. An analysis with an optimization technique, three new equations can be used as an easy-to-implement calculation approach for heat sink design in electronic thermal management.

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Effect of thermal boundary conditions and thermal conductivity on conjugate heat transfer performance in pin fin arrays

Weihong Li*, Li Yang, Jing Ren, Hongfei Jiang

Jiao Jiahua Institute, Tonghua University, Jilin, China

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Pin fin array
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Thermal boundary conditions
Transient liquid crystal
Steady liquid crystal

ABSTRACT

The present work experimentally investigates the conjugate heat transfer performance for pin fin arrays. The geometry of pin fin arrays is typical of $0.5 \times 0.5 \times 1$ and $1 \times 1 \times 1$. The effects of **thermal boundary conditions**, material thermal conductivity and thermal boundary conditions, i.e. conjugate and **convective boundary conditions**, are quantified by comparing the thermohydraulic performance and **heat transfer**.

For conjugate heat transfer, models are constructed with materials with thermal conductivity ranging from 0.25 W/m² K to 16 W/m² K. Isothermal heat flux is imposed along the external wall of pin fin arrays and highly resolved temperature distributions of internal wall is obtained with steady liquid crystal, meanwhile external wall temperature is measured through thermocouples. For convective heat transfer, model is constructed with low thermal conductivity material to ensure the range of transition liquid crystal to detect heat transfer coefficients of the internal wall on the same configuration.

Experimental data of temperature and heat transfer coefficient distribution is used as boundary conditions to conduct FEM calculations of pin fin arrays. Internal and external wall one-dimensional temperature distributions, as well as three-dimensional distributions of the whole domain are compared. Results indicate that thermal conductivity can significantly impact the heat transfer capacity, on transient state heat transfer, meanwhile, the necessity of taking conjugate heat transfer effect is demonstrated by comparison with purely convective results.

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Estudos Recentes

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Numerical and experimental study of natural convection heat transfer characteristics for vertical plate fin and tube heat exchangers with various tube diameters

Han-Taw Chen ^{a,*}, Yung-Shiang Lin ^a, Pin-Chun Chen ^a, Jiang-Ren Chang ^b^a Department of Mechanical Engineering, National Cheng Kung University, Tainan 701, Taiwan^b Department of Business Engineering and Rural Architecture, National Taiwan Ocean University, Keelung 992, Taiwan

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ABSTRACT

This study uses three-dimensional computational fluid dynamics commercial package along with experimental data and various flow models to investigate the natural convection heat transfer and fluid flow characteristics of a single-tube vertical plate fin and tube heat exchangers for various values of fin spacing and tube diameter. Temperature and velocity distributions of **vertical** fin, tube fin, fin temperature and heat transfer coefficient on the fin are determined using **CFD** along with various flow models. The inverse method in conjunction with the finite difference method and the experimental temperature data is applied to determine the fin temperature and heat transfer coefficient for the studied tube. More accurate results can be obtained, if the heat transfer coefficient obtained is close to the inverse results and matches existing correlations. The numerical results of the fin temperature at the selected measurement locations also coincide with the experimental temperature data. The results show that K&G A-s turbulence model is more suitable for this problem than laminar flow model. These proposed new correlations between the Nusselt number and the Rayleigh number are in good agreement with the inverse results and numerical results obtained.

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Research Paper

Convection–radiation heat transfer study of moving fin with temperature-dependent thermal conductivity, heat transfer coefficient and heat generation

A.S. Dogançhi, D.D. Gargi ^{*}

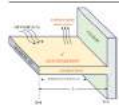
Mechanical Engineering Department, Indian Institute of Technology (IIT) Bombay, India



HIGHLIGHTS

- Convection–radiation Moving fin.
- Application of 2D M which is an analytical solution technique.
- Temperature-dependent thermal conductivity, heat transfer coefficient and heat generation.
- Study of the effects of thermal parameters on temperature distribution.
- Get the optimal temperature distribution between even cases.

GRAPHICAL ABSTRACT



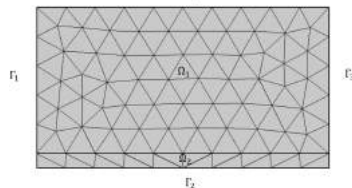
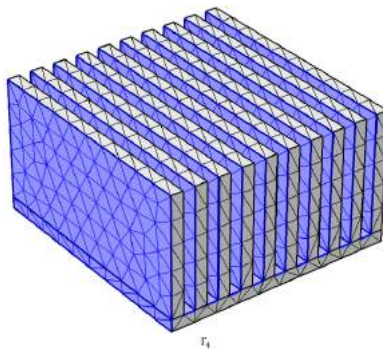
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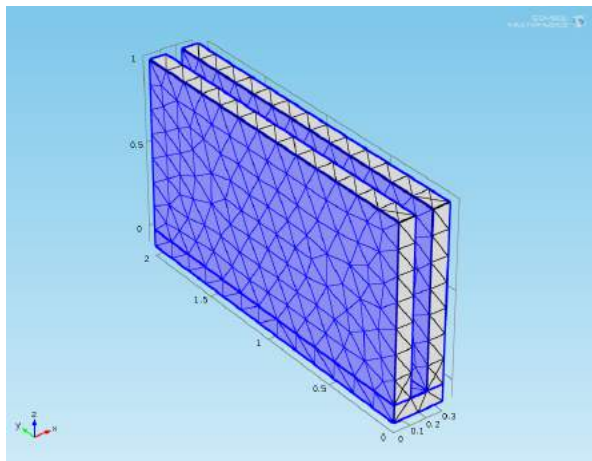
ABSTRACT

In this article, the convection–radiation heat transfer study of moving fin with heat generation is studied. The heat transfer coefficient, thermal conductivity and heat generation are variable and dependent on temperature-dependent. The heat transfer is studied using long fin and rectangular fin and was carried out by using the Differential Transformation Method (DTM). The results indicate that the fin temperature decreases with an increase in the heat generation and also decreases in the fin.

Modelo Físico



Modelo Físico



Murray-Gardner

- Temperatura não nula do dissipador;
- Interação entre aletas e superfície primária;
- Condutividade térmica dependente da temperatura;
- Irradiação mútua entre aletas adjacentes;
- Efeito combinado de irradiação mútua e radiação ambiental;
- Interação da radiação com a estrutura associada.

Fonte: KRAUS, Allan D.; AZIZ, Abdul; WELTY, James. Extended surface heat transfer. John Wiley & Sons, 2002.

Formulação Matemática

$$\frac{\partial}{\partial x} \left(k(T) \frac{\partial \bar{T}}{\partial x} \right) + \frac{\partial}{\partial y} \left(k(T) \frac{\partial \bar{T}}{\partial y} \right) - \frac{2}{\delta} \left[h(\bar{T} - T_{\infty}) + \epsilon \sigma |\bar{T}|^3 \cdot \bar{T} \right] = 0 \quad \text{in } \Omega_1$$

$$-k \nabla \bar{T} \cdot \mathbf{n} = 0 \quad \text{on } \partial \Omega_1 = \Gamma_1 \cup \Gamma_3 \cup \Gamma_4$$

and

$$T = T_{env}(\xi, \eta) \quad \text{for } t = 0; 1 < \xi < H; 1 < \eta < Z$$

Fonte: WEBB, Ralph L.; KIM, Nae-Hyun. Principles of enhanced heat transfer. Taylor Francis: New York, NY, USA, 2005.

Transformada de Kirchhoff

Redução da equação do calor a uma equação diferencial parcial linear por meio da introdução de nova variável ω relacionada com T da seguinte forma:

$$\omega = f(T) = \int_{T_0}^T k(\epsilon) d\epsilon$$

Transformada de Kirchhoff

Para curva empírica do cobre com o auxílio do método dos mínimos quadrados, obteve-se a seguinte curva ajustada a ser integrada na Transformada de Kirchhoff:

$$\omega = f(T) = \int_{T_0}^T k(\epsilon) d\epsilon = \frac{c}{(d+1)} \cdot T^{(d+1)}$$

$$\text{grad}\omega = k \text{grad}T$$

$$T = f^{-1}(\omega) = e^{\frac{1}{d+1} \log \frac{\omega(d+1)}{c}}$$

Transformada de Kirchhoff

$$\operatorname{div}[\operatorname{grad}\omega] - \frac{2}{\delta} \left[h.e^\lambda + \sigma|e^\lambda|^3.e^\lambda \right] = 0 \quad \text{in } \Omega_1$$

com condição de contorno

$$-(\operatorname{grad}\omega).\mathbf{n} = 0 \quad \text{on } \partial\Omega_1.$$

Formulação Variacional

Solução do problema físico real deve ser alcançada através do limite da sequência cujos elementos são obtidos através da minimização do seguinte funcional quadrático:

$$I[\nu] = \frac{1}{2} \int_0^H \int_0^Z \left[\left(\frac{\partial \nu}{\partial x} \right)^2 + \left(\frac{\partial \nu}{\partial y} \right)^2 \right] dx dy + \int_0^H \int_0^Z \left[\frac{h}{\delta k} (\nu - T_\infty)^+ \frac{2\varepsilon\sigma}{5Dk} |\nu|^5 \right] dx dy$$

A primeira variação do funcional descreve a formulação variacional do problema real

Fonte: Martins-Costa, M.L., de Freitas Rachid, F.B. and da Gama, R.M.S., 2016. "An unconstrained mathematical description for conduction heat transfer problems with linear temperature-dependent thermal conductivity". International Journal of Non-Linear Mechanics, Vol. 81, pp. 310–315.

Sequência de Problemas Lineares

$$\omega = \lim_{i \rightarrow \infty} \Phi_i$$

em que os elementos da sequência $[\Phi_0, \Phi_1, \Phi_2, \dots, \Phi_i]$ são obtidos através de


$$\operatorname{div}(\operatorname{grad} \Phi_{i+1}) = \alpha \Phi_{i+1} - \beta_i \quad \text{in } \Omega_1$$

e

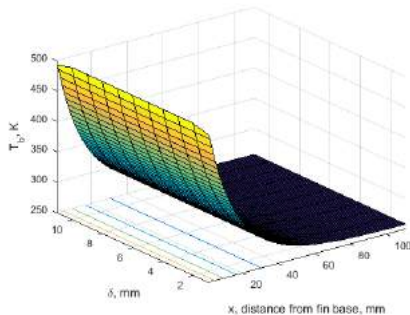
$$-(\operatorname{grad} \Phi_{i+1}) \mathbf{n} = 0 \quad \text{on } \partial \Omega_1$$

Para um termo auxiliar β :

$$\beta_i = \alpha \Phi_{i-1} - \left(\sigma |\Phi_{i-1}|^3 \Phi_{i-1} - h(\Phi_{i-1} - T_\infty) \right) \quad \text{for } i = 0, 1, 2, \dots$$

Fonte: Gama, R.M.S., Corrêa, E.D. and Martins-Costa, M.L., 2013. "An upper bound for the steady-state temperature for a class of heat conduction problems wherein the thermal conductivity is temperature dependent"  International Journal of Engineering Science, Vol. 69, pp. 77–83.

Perfil de Temperatura



Aletas longitudinais de cobre com C.C. convectivas e radiativas de perfil retangular

Discretização em 11 nós

	1	2	3	4	5	6	7	8	9	10	11
1	276.9028	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
2	280	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
3	280	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
4	280	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
5	280	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
6	280	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
7	280	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
8	280	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
9	280	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
10	280	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293
11	276.9028	273.8056	268.7513	264.6555	261.3740	258.7933	256.8257	255.4046	254.4827	254.0293	254.0293

Base a T_{amb} C.C. convectiva

	1	2	3	4	5	6	7	8	9	10	11
1	279.6022	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
2	280	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
3	280	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
4	280	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
5	280	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
6	280	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
7	280	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
8	280	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
9	280	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
10	280	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320
11	279.6022	279.2044	278.5328	277.9719	277.5105	277.1392	276.8508	276.6393	276.5007	276.4320	276.4320

Base a T_{amb} C.C. convectiva e radiativa

Conclusão

- A influência da temperatura na condutividade térmica (dando origem a equações diferenciais não lineares). Tal dependência é muito importante quando existem grandes variações de temperatura
- A influência da radiação térmica nos processos de troca de calor (gerando também não linearidades). Tal influência fica mais importante quando as temperaturas envolvidas são altas e/ou as atmosferas são rarefeitas

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Agradecimento

Obrigado a todos !