A Comparison of Commercial CFD Software Capable of Coupling to External Electromagnetic Software for Modeling of Microwave Heating Process

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***Abstract* -** The available simulation tools, developed to meet the demands of telecommunications industry, lack the features that are crucial in microwave power engineering to ensure high accuracy of simulations of microwave heating effect. It seems that one of methods to obtain an ideal tool for microwave power specialists would be to couple a piece of commercial electromagnetic software with an external CFD code which would handle all non-electrodynamic effects. In this paper several such CFD packages has been reviewed.

Introduction

Microwave heating is gaining popularity in a variety of applications. More and more often it is introduced into technological processes in the food, timber, ceramic and many other industries, where this source of heat has an advantage over conventional solutions since it takes up less space on work floor, can raise the temperature of heated samples faster and is cheaper. Also, the well known domestic microwave ovens are found is a growing number of households. These constantly expanding applications of microwave heating feed interest in search for methods for fast Computer Aided Design techniques that would facilitate the design of such devices.

In the design of effective and cheap microwave power applicators it is necessary to take into account not only the electromagnetic phenomena but also a large variety of thermal and fluid flow effects. An ideal numerical tool for a microwave heating specialists and the microwave power industry should integrate modern achievements in numerical and modeling techniques employed in electrodynamics, thermodynamics and flow dynamics. Unfortunately, no such perfect tool exists – instead one finds many separate packages for electromagnetics and thermodynamics.

Electromagnetic simulation tools based on FEM (*Finite Element Method*) or FDTD (*Finite Difference Time Domain*) are well known to both practitioners and scientists working in the field of microwave techniques. One of the first industries that took advantage of the technology was telecommunications. As a result, on the market one can find a plethora of commercial electromagnetic packages originally developed for telecommunication applications. Because of their background, the available codes lack the features that are crucial to ensure high accuracy of simulations of processes like microwave heating. On the other hand, the existing CFD codes offer the features necessary to accurately solve the thermal and flow problems, but they are not equipped with electromagnetic modules.

Hence, one of the ways to obtain the aforementioned ideal tool is to couple two separate commercial solvers: an electromagnetic and a CFD package. Such an approach can lead to an efficient simulation system, capable of delivering reliable results, because it would be based on components that have been already tested and verified in many practical projects. Another advantage is an increased flexibility with the choice of components of such a system.

The purpose of this paper is to put together information on the existing CFD software that is already in use in academia and industry. Comparisons similar to the one presented in this paper are difficult to come by in the open literature. This can be attributed to the high costs of CFD software, which makes it expensive to buy and train personnel in using a few of such packages. In [1] one can find comparison of CFD software, in which the performance of several packages has been compared using flow problems benchmarks. General considerations that should be taken into account while choosing a suitable CFD package have been presented in [2]. Also, it is possible to find data on validation of some codes against theoretical expectations found in the literature (e.g. [3]). However, our specific target is to compare the CFD codes from the viewpoint of coupling to electromagnetic solvers.

Criteria for the Software

The software packages that appear in this paper have been reviewed based on how easy or difficult it is to couple them to an external electromagnetic solver and perform a full simulation of the microwave heating process. One such simulation will start with an electromagnetic analysis for some initial period of time, in order to obtain the steady-state microwave power distribution within the heated object. Then the thermal solver should be invoked, so that the temperature diffusion can be calculated and returned back to the electromagnetic simulator. The electromagnetic simulator will then automatically modify media parameters in accordance with enthalpy or temperature pattern [4, and continue the analysis until the next electromagnetic steady-state.

The simulation will involve exchanging the data between two solvers many times, which excludes the possibility of having a human operating both packages. This is why the CFD software needs to offer several features allowing for automatization of this task as well as other features inherent to thermal behaviour of foods:

- **External mesh import from a text file of known format**
- **Import of initial conditions**
- **Import of boundary conditions**
- **Batch mode of operation**
- **Possibility to define temperature dependence of the media parameters**
- **Possibility to model heat flow through porous media**
- **Possibility to model the phase change in heat conduction**

Another criterion for the software is the ease of use. This is an important factor especially because in this particular application – microwave heating modeling – the operators of the software may come from different disciplines than thermodynamics and not be fully prepared to cope with additional difficulties caused by the quirks of the software interface. In general, it is the commercial products that fulfill this requirement and this is why only the commercial codes have been included in the comparison. Also the data available for academic codes have been often unavailable or fragmented.

Results of the Comparison

The names and the data on all the CFD packages taken into consideration in this comparison have been presented in Table 1. In some cases one company has a few codes for modeling flow and thermal problems. It is especially true with ANSYS which offers a broad range of products suited for various applications. Some of them are fully-fledged CFD packages (CFX, Flotran) while other ones are more general-purpose but offer transient heat transfer as one of the options.

The numerical method employed by the developers of packages is either FEM method or FVM (*Finite Volume Method*). It is believed that FVM method is superior to FEM in all those applications where flows play an important role. For example, Fluent's Fluent software, a FVM package, is generally recommended for flow problems by Fluent representatives. Nevertheless, there are advanced FEM-based packages that have been successfully employed in flow problems (ADINA, Abaqus, ALGOR, or Marc).

The phase change models employed in the reviewed software are based either on enthalpy or latent heat. The latent heat approach, although popular, requires caution with implementation, and especially time integration algorithms. This is due to the spike-shaped temperature/specific heat function. The enthalpy-based phase change models evaluate the effective specific heat directly from the enthalpy, and thus avoid using specific heat function with a latent heat jump. Some codes (e.g. FIDAP) offer several enthalpy models for the user to choose from. Other ones (ADINA, Abaqus, or ALGOR) simulate the phase change effect with improved latent heat method where the careful positioning of the aforementioned jump on the specific heat curve alleviates computational problems.

The overall majority of the packages allow reading external files with data on mesh, initial and boundary conditions, which makes them good candidates for being used in the coupled system. Those that do not offer one of those features could be still applied, but it would require an extensive help from a humane operator making the simulation more difficult.

Conclusion

Many commercial electromagnetic packages available on the market have been originally developed for telecommunication applications. Because of their background those codes often lack the features that are crucial in microwave power engineering to ensure high accuracy of simulations of processes like microwave heating effect.

Building a simulation system that would consist of one commercial electromagnetic code and a separate commercial CFD package seems to be an interesting possibility. In this paper we have reviewed features of several CFD packages that could be coupled to an external electromagnetic code. The goal of this comparison was not to reveal a winner, but to gather the data on various codes, and show possible choices.

Table 1.

Company	Code	Price	Operating system and requirements
ANSYS, Inc. www.ansys.com	CFX 5.1	Call Vendor	UNIX Compaq/HP/SUN/SGI/IBM Windows NT/2000/XP; Linux Redhat 7.3
	Flotran 7.1	€20k[0,2] (+20%)[4]	Windows 2000/XP; Linux; UNIX Compaq/HP/IBM/SGI/Sun
	Multiphysics 7.1	€7k[1] €60k[0,2] (+20%)[4]	Windows 2000/XP; Linux UNIX Compaq/HP/IBM/SGI/Sun
	Design Space 7.1	€0.6k[1]; €5-10k[0,2]	Windows XP/2000/NT 4.0; UNIX HP/Sun 128MB RAM; 500MB HDD
	Mechanical 7.1	€40k[0,2]	Windows 2000/XP; Linux UNIX Compaq/HP/IBM/SGI/Sun
	Professional 7.1	€18.5k[0,2]	Windows 2000/XP; Linux UNIX Compaq/HP/IBM/SGI/Sun
ADINA, Inc. www.adina.com	Adina-T	$1.8k[1]	Windows, UNIX
	Adina-F	$1.8k[1]; $21k[0,2]	
MSC.Software Corp. www.mscsoftware. com	Marc 2003	$25k[0,2]	Windows NT/2000; Linux UNIX Sun/HP/IBM/SGI/Compaq
	Nastran + Heat Transfer Pro	$40k[0,2]	Windows NT/2000; Linux; UNIX Sun/HP/IBM/SGI/Compaq/Cray/Fujitsu/Nec
	Patran Thermal 2003	$20k[0,2]	Windows 2000/XP UNIX Sun/HP/IBM/SGI; Linux
CHAM Ltd. www.cham.co.uk	Phoenics	€5k[1] (+ €0.9k)[4]; €15k[2]; €3.75k[3] (+€2.2k)[4]	Windows 95/98/2000/XP; Linux; UNIX
Adaptive Research Corp. www.adaptive-research.com	STORM/CFD2000 4.11	Call Vendor	Windows
ALGOR, Inc. www.algor.com	ALGOR Professional Heat Transfer	$0.99k[1]; $4.95-k[2]; Call Vendor[3,4]	Windows 98/2000/NT/Me/XP
	ALGOR Professional Fluid Flow	$1.59k[1]; $7.95k[2] Call Vendor[3,4]	
	ALGOR Professional Multiphysics	$5.09k[1]; $25.45k[2]; Call Vendor[3,4]	
Flow Science, Inc. www.flow3d.com	FLOW-3D 8.2	$2k[1,3]; $4k[1,3,4] $11k[1,2]	Windows NT/XP/2000; Linux UNIX DEC/HP/IBM/Sun/SGI

CD adapco Group www.cd-adapco.com	Star-CD 3.2	Call Vendor	Windows; UNIX HP/SGI/IBM; Linux
Vector Fields Ltd. www.vectorfields.com	Opera 3D Tempo	Call Vendor	Windows 98/Me/NT/2000/XP; UNIX SUN/HP/SGI; 512MB RAM; >1GB HDD
Fluent, Inc. www.fluent.com	Fluent 6.1	£2.5k[1]; $12k[0,3,4]	Windows NT/2000/XP; UNIX SGI/HP/IBM/SUN; Linux Red Hat/SuSe 256MB RAM; 100 MB HDD
	Fidap 8.6	£2.5k[1]; $12k[0,3,4]	Windows NT/2000/XP; UNIX SGI/HP/IBM/SUN
Abaqus, Inc. www.abaqus.com	Abaqus 6.4	€2.5k[1] €15k[3,4]	Windows XP/2000; Linux; UNIX Compaq/HP/SGI/IBM
Softflo www.softflo.com	Flo++ 3.08	$0.6k[1] $1.8k[2] (+$0.6k)[4]	Windows NT/95/98 64MB RAM; >50MB HDD
SolidWorks Corp. www.solidworks.com	COSMOSFloWork	Call Vendor	Windows XP/2000/Me/98 256MB RAM; >200MB HDD
	COSMOSM		
	COSMOSWorks		
	COSMOSDesign STAR		

[0] commercial license; [1]educational license; [2] permanent license; [3] one-year license; [4] technical support

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The following software developers delivered information on characteristics, technical details and features of their codes: Abaqus, Inc. Adina, Inc.; ALGOR, Inc.; ANSYS, Inc.; CHAM, Ltd.; Computational Dynamics, Ltd.; Flow Science, Inc.; Fluent, Inc.; MSC Software, Corp.; Softflo; SolidWorks, Corp.; Vector Fields, Ltd. Authors kindly acknowledge the help of Andrzej Bienkowski of the Dept. of Production Engineering of Warsaw University of Technology with obtaining data on ADINA software.

References

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Table 1 (con'd).

Code	Method	Thermal boundary conditions	Import			batch mode	temp.. dependence	Phase change model
			Mesh	BC	IC			
CFX 5.1	FEM	Temperature, flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	✓
Flotran 7.1	FEM	Temperature., flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	E
Multiphysics 7.1	FEM	Temperature, flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	E
Design Space 7.1	FEM	Temperature, flux, convection	✓	✓	✓	✓	✓	✗
Mechanical 7.1	FEM	Temperature, flux, convection, radiation	✓	✓	✓	✓	✓	E
Proffesional 7.1	FEM	Temperature, flux, convection, radiation	✓	✓	✓	✓	✓	E
Adina-T	FEM	Temperature, flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	L
Adina-F	FEM	Temperature, flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	L
Marc 2003	FEM	Temperature, flux, convection, radiation	✓	✓	✓	✓	✓	L
Nastran + Heat Transfer Pro	FEM	Temperature, flux, nodal power, radiation	✓	✓	✓	✓	✓	L
Patran Thermal 2003	FEM	Temperature, flux, convection, radiation, heat sources,	✓	✓	✓	✓	✓	L
Phoenics	FEM	Temperature, flux, convection, radiation	✓	✓	✓	✓	✓	**E, L**
STORM/CFD2000 4.11	FVM	Temperature, flux, convection, radiation	Call Vendor					✓
ALGOR Professional Heat Transfer	FEM	Temperature, flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	L
ALGOR Professional Fluid Flow	FEM	Convection	✓	✓	✓	✓	✓	L
ALGOR Professional Multiphysics	FEM	Temperature, flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	L
FLOW-3D 8.2	FVM	Temperature, flux, convection, radiation, heat sources,	✗	✓	✗	✓	✓	E
Star-CD 3.2	FVM	Temperature, flux, convection, radiation	✓	✓	✓	✓	✓	E
Opera 3D Tempo	FEM	Temperature, flux, convection	✗	✓	✓	✓		✗
Fluent 6.1	FVM	Temperature, flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	E
Fidap 8.6	FEM	Temperature, flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	E

Abaqus 6.4	FEM	Temperature, flux, convection, radiation	✓	✓	✓	✓	✓	L
Flo++ 3.08	FVM	Temperature, flux, convection, radiation	✓	×	×	✓	✓	×
COSMOSFloWork	FVM	Temperature, radiation, heat sources	×	×	×	✓	✓	×
COSMOSM	FEM	Temperature, flux, convection, radiation, heat sources	✓	✓	✓	✓	✓	×
COSMOSWorks	FEM	Temperature, flux, convection, radiation, heat sources	×	×	×	✓	✓	×
COSMOSDesign STAR	FEM	Temperature, flux, convection, radiation, heat sources	×	×	×	✓	✓	×

FEM – Finite Element Method; FVM – Finite Volume Method; ✓ – feature available; × – feature unavailable;
E – enthalpy-based phase change model; L – latent heat based phase change model

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