

UNCLASSIFIED

Defense Technical Information Center
Compilation Part Notice

ADP012366

TITLE: The RCM2 10 Bars Test Case. Combustion of Cryogenic Propellant at 10 Bars Using the CPS Code

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: 2nd International Workshop on Rocket Combustion Modeling: Atomization, Combustion and Heat Transfer held in Lampoldshausen, Germany on 25-27 Mar 2001

To order the complete compilation report, use: ADA402618

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP012355 thru ADP012373

UNCLASSIFIED

The RCM2 10 bars test case

Combustion of cryogenic propellant at 10 bars using the CPS code

**2nd International Workshop on Rocket Combustion Modelling
Lampoldshausen March 25-27, 2001**

Presented by Laurent Lequette from Bertin Technologies

2nd RCM Workshop : RCM2 10 bars test case

1

The introduction

2

The objectives and the approach

3

The main results

4

The numerical and the physical models

5

The results presentation

6

The conclusion

2nd RCM Workshop : RCM2 10 bars test case

The introduction

1

- ❑ Bertin Technologies
 - ❑ technological services provider and consultancy
 - ❑ French private company
 - ❑ staff : 250 employees
- ❑ The SIMA team
 - ❑ working in Information Systems and Advanced Modelling
 - ❑ has been involved in CFD modelling for more than 15 years and has developed several CFD tools like CALIFE, THESEE and now CPS
- ❑ This work has been founded by CNES

2nd RCM Workshop : RCM2 10 bars test case

The introduction

The CPS code

- ☐ new generation CFD code
 - ☐ unstructured meshes (3D)
 - ☐ Roe and Toumi formulation for Euler fluxes
 - ☐ explicit and implicit schemes (for steady and for unsteady flows)
 - ☐ turbulence models (Jones-Launder, Coakley, RNG, subgrid, ...)
 - ☐ Eulerian two phases model
 - ☐ Lagrangian two phases model (LASVEGAS)
 - ☐ atomisation and coalescence
 - ☐ arbitrary time step
 - ☐ high volumic rates
 - ☐ Combustion models (Arrhenius, TECK, flame surface)
- ☐ developed by Bertin Technologies and SNPE Group together
 - ☐ benefits from earlier developments of both companies
- ☐ a commercial version is being launched
 - ☐ we are looking for pilot customers

2nd RCM Workshop : RCM2 10 bars test case

The objectives and the approach

- ☐ The objectives
 - ☐ To assess the most recent developments of CPS for cryogenic applications
 - ☐ To retrieve guidelines for future developments of CPS
 - ☐ numerical point of view
 - ☐ physical models
- ☐ The approach
 - ☐ Lagrangian two phases models (LASVEGAS model)
 - ☐ Use of CPS from an engineer point of view
 - ☐ Use of standard options only
 - ☐ No special treatment for the injection area
 - ☐ No parameters tuning
 - ☐ Start from zero with all the models activated
 - ☐ Comparison of normal Lox injection (3 m/s) and accelerated (10 m/s) as recommended for the WS

2nd RCM Workshop : RCM2 10 bars test case

The main results

- ☐ No major numerical difficulty using the explicit Roe-Toumi scheme, but
 - ☐ it has not been possible to inject inside the Lox injector
 - ☐ the implicit scheme is not robust enough for such an application
- ☐ The results are sensitive to the laminar binary diffusion coefficients values
- ☐ The results are not very sensitive to the use of the Rosin-Rammler distribution instead of constant diameters
- ☐ Some improvements of the injection area have to be done
 - ☐ it is not clear where the added Lox quantity of movements comes from, for the 10 m/s injection case
- ☐ The maximum temperature is around 2500 K and the pressure close to 10 bars
 - ☐ it seems to be close from experimental values

2nd RCM Workshop : RCM2 10 bars test case

The numerical and the physical models

4

- ☐ Numerical models and parameters
 - ☐ second order Roe-Toumi explicit scheme
 - ☐ CFL 0.5
 - ☐ steady state optimisation (local time steps for gas)
 - ☐ unsteady approach for droplets
- ☐ Physical models and parameters
 - ☐ Mixing of perfect gas (H₂, O₂ and H₂O)
 - ☐ varying Cp and Cv
 - ☐ laminar viscosities function of the temperature
 - ☐ Coakley (q,ω) turbulence model
 - ☐ LASVEGAS Lagrangian two phases model
 - ☐ TECK combustion model (improved EBU-Arrhenius model)
- ☐ Mesh
 - ☐ 3880 elements
 - ☐ Whole domain including the nozzle

2nd RCM Workshop : RCM2 10 bars test case

The numerical and the physical models

- ☐ GH2 Inlet boundary conditions : mass flow rate and total temperature fixed
 - ☐ $Q = 267.96 \text{ kg m}^{-2} \text{ s}^{-1}$ $T_t = 290.56 \text{ K}$
 - ☐ $k = 380 \text{ m}^2 \text{ s}^{-2}$ $\omega = 800 \text{ s}^{-1}$
- ☐ Outlet boundary conditions : fixed pressure
 - ☐ $P_s = 39.7 \cdot 10^5 \text{ Pa}$ $T_s = 293. \text{ K}$ (for reentrant flow only)
 - ☐ $k = 10 \text{ m}^2 \text{ s}^{-2}$ $\omega = 100 \text{ s}^{-1}$ (for reentrant flow only)
- ☐ Lox Injector
 - ☐ $T = 85 \text{ K}$ $Q = 2546.5 \text{ kg m}^{-2} \text{ s}^{-1}$ $v = 2.18 \text{ m/s}$ or 10 m/s
 - ☐ Rosin-Ramler diameters distribution
 - ☐ equivalent to a wall for the gas
- ☐ Walls
 - ☐ adiabatic
 - ☐ turbulent law of the wall
 - ☐ tangential film for impacting droplets

2nd RCM Workshop : RCM2 10 bars test case

The numerical and the physical models

4

- ☐ Chemistry parameters for TECK model
 - ☐ Activation temperature 2000 K
 - ☐ Pre-exponential coefficient 10^{12}
 - ☐ H2 and O2 partial orders 1.
 - ☐ Threshold temperature 300 K
- ☐ Binary diffusion coefficients
 - ☐ $D_{A,B} = 1.013 \cdot 10^{-7} T^{-1.75} (1/M_A + 1/M_B)^{1/2} / P / (V_A^{1/3} + V_B^{1/3})$
 - ☐ with P defined in bars, M in g/mole
 - ☐ $V_{O_2} = 16.6$ $V_{H_2} = 7.07$ $V_{H_2O} = 12.7$
- ☐ Thermal conductivities
 - ☐ function of temperature
- ☐ Initial conditions
 - ☐ $P_s = 10^5$ Pa $T_s = 300$ K $v = 100$ m s⁻¹
 - ☐ $Y_{H_2} = 1$. $K = 200$ m² s⁻² $\omega = 100$ ms⁻¹

2nd RCM Workshop : RCM2 10 bars test case

The results

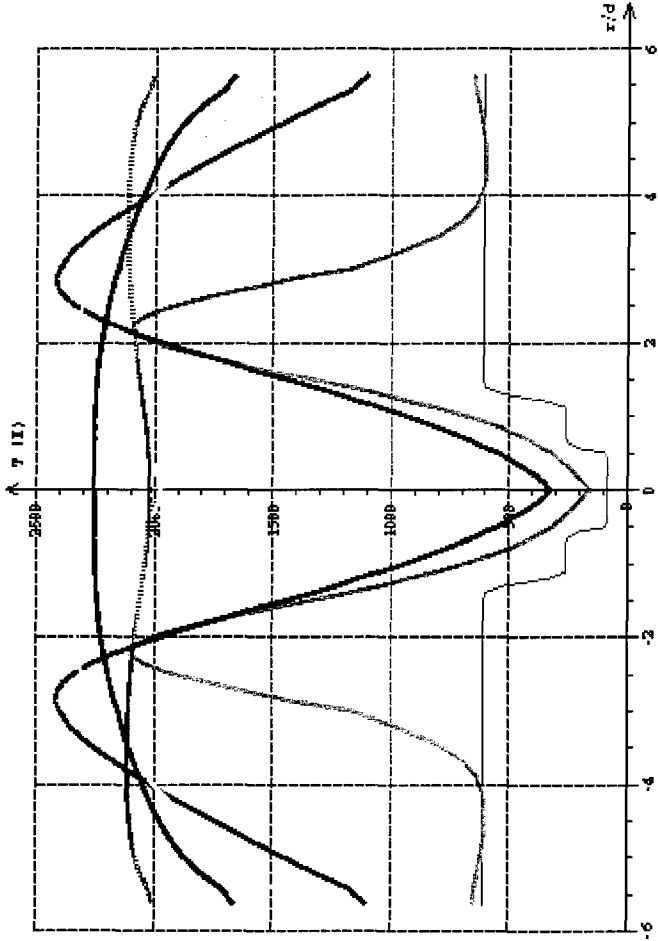
- ☐ Some results may not be thoroughly converged but all of them are converged in the combustion area
- ☐ As a single reaction model was used, OH fractions cannot be presented, but the production rate for temperature can be used to visualise the flame location

2nd RCM Workshop : RCM2 10 bars test case

The results

Temperature
RCM2 2D : monodisperse case
droplet diameter = 110 microns

n : 270933
mini: 85.371
maxi: 2418.7



Temperature $x = 0$ m
Temperature $x = 5$ m
Temperature $x = 6$ m
Temperature $x = 12$ m
Temperature $x = 15$ m

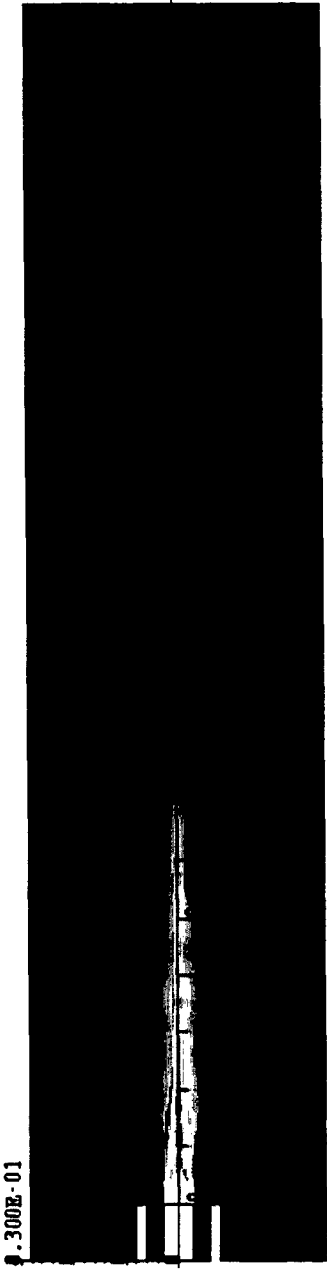
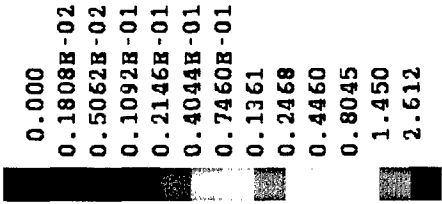


2nd RCM Workshop : RCM2 10 bars test case

The results

Volumic rate for the polydispersed phase
RCM2 2D : monodisperse case
droplet diameter = 110 microns

n : 270993
mini: 0.0000
maxi: 4.7030



2nd RCM Workshop : RCM2 10 bars test case

The results

Reactive rate (mole/kg/s)
RCM2 2D : monodisperse case
droplet diameter = 110 microns

n : 270993
mini: 8.02469E-09
maxi: 1.75812E+06

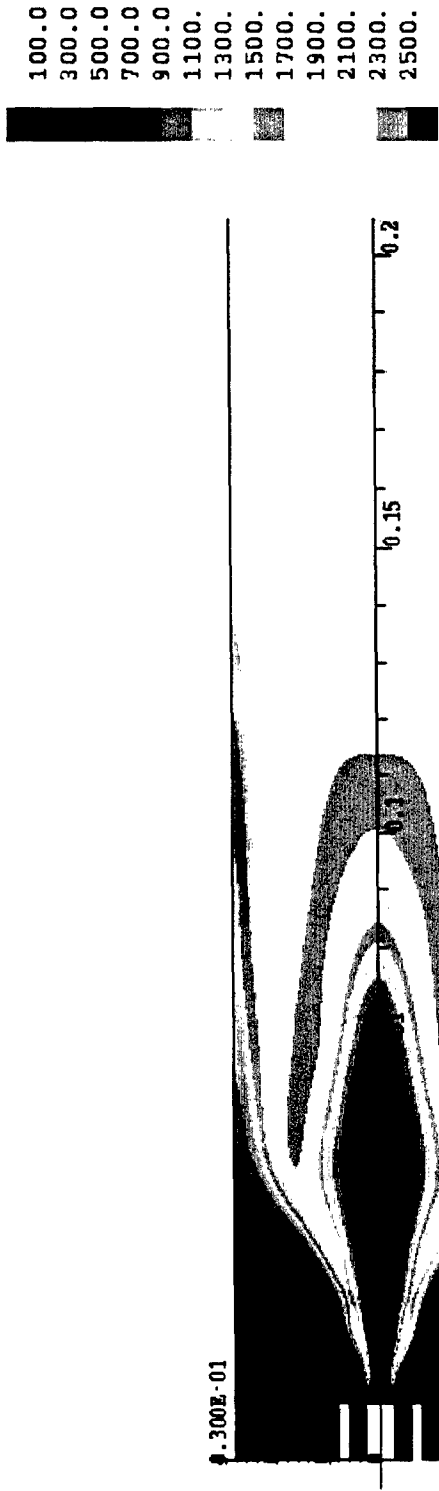


2nd RCM Workshop : RCM2 10 bars test case

The results

Temperature
RCM2 2D : monodisperse case
droplet diameter = 110 microns

n : 270993
mini: 85.371
maxi: 2418.7

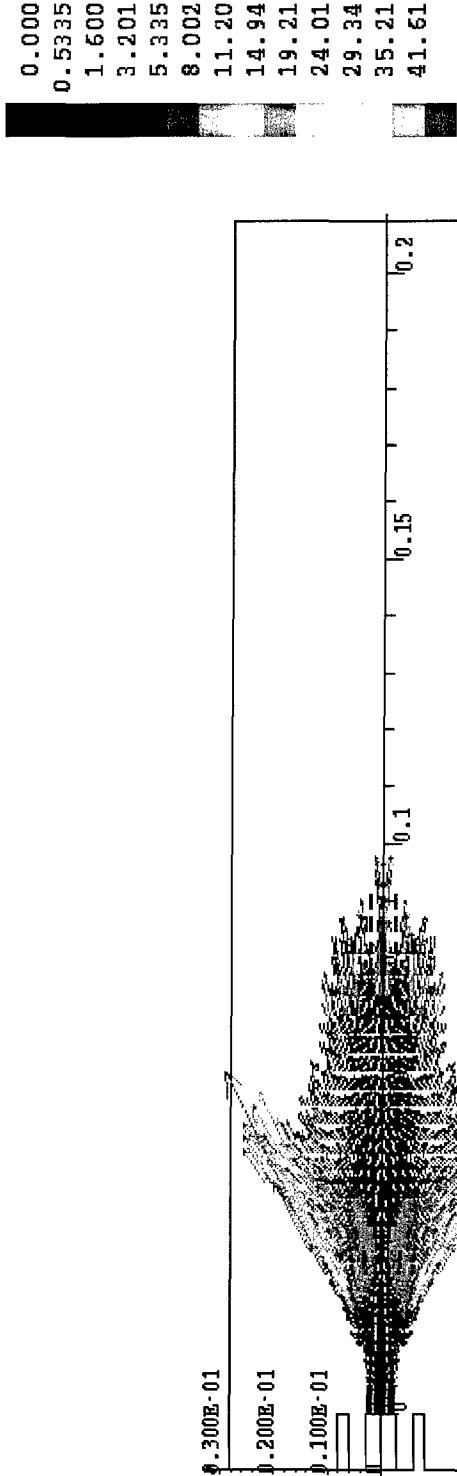


2nd RCM Workshop : RCM2 10 bars test case

The results

Velocity vectors of the dispersed phase
RCM2 2D : monodisperse case
droplet diameter = 110 microns

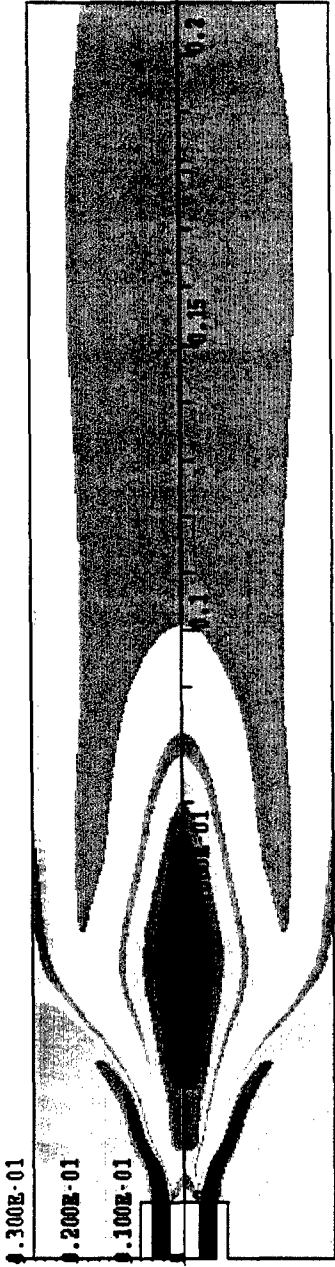
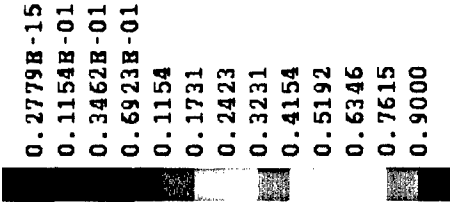
n : 270993
mini: 0.0000
maxi: 41.611



2nd RCM Workshop : RCM2 10 bars test case
The results

Massic fraction of H2O
RCM2 2D : nonodisperse case
droplet diameter = 110 microns

n : 270993
mini: 2.77865E-16
maxi: 0.87504



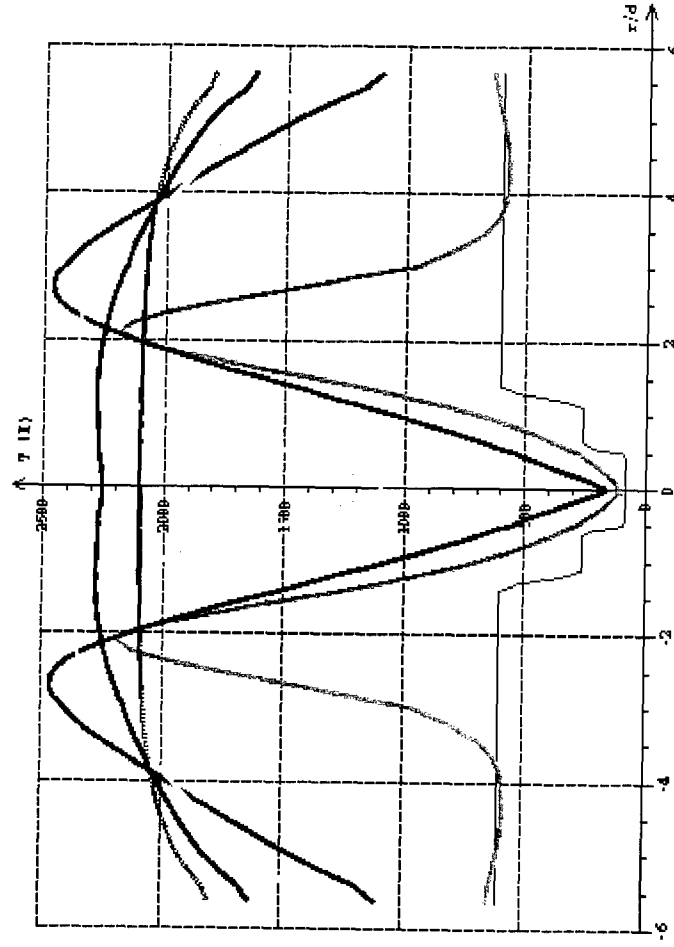
2nd RCM Workshop : RCM2 10 bars test case The results

5

Temperature

RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution

n : 134004
mini: 81.648
maxi: 2483.5



Temperature at $x = 0$ ms

Temperature at $x = 3$ ms

Temperature at $x = 6$ ms

Temperature at $x = 12$ ms

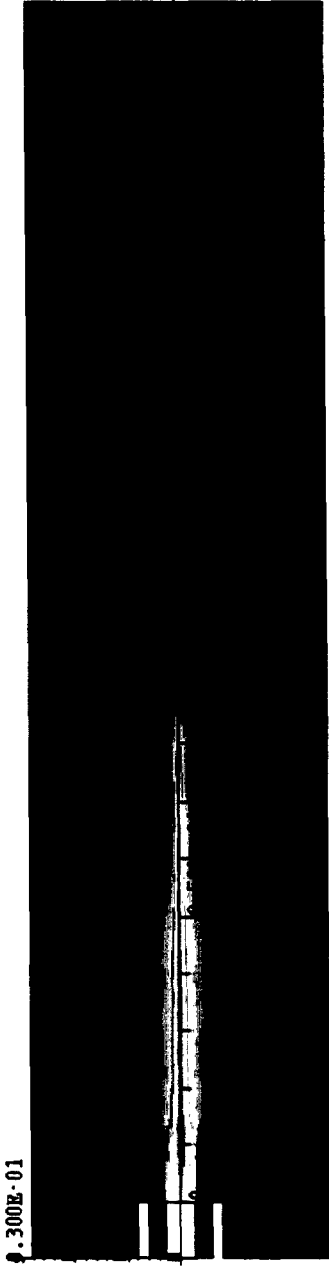
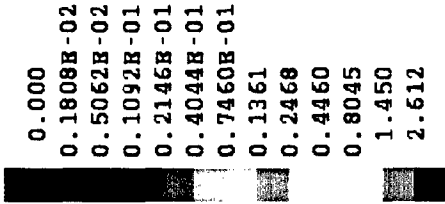
Temperature at $x = 15$ ms

2nd RCM Workshop : RCM2 10 bars test case

The results

Volumic rate for the polydispersed phase
RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution

n :	134004
mini :	0.0000
maxi :	4.3172



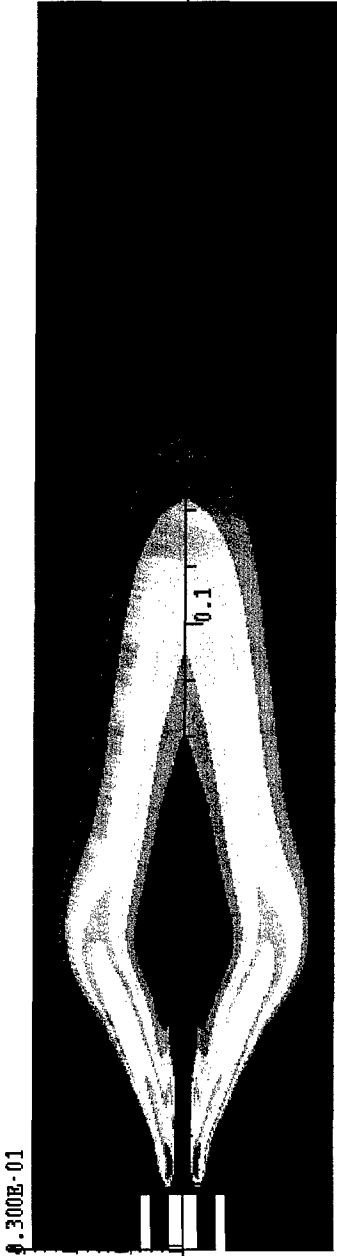
2nd RCM Workshop : RCM2 10 bars test case

The results

Reactive rate (mole/kg/s)
RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution

n : 134004
mini: 8.02469E-09
maxi: 2.69424E+06

0.1000E-07
675.8
1892.
4082.
8023.
0.1512E+05
0.2789E+05
0.5087E+05
0.9224E+05
0.1667E+06
0.3008E+06
0.5420E+06
0.9764E+06



2nd RCM Workshop : RCM2 10 bars test case
The results

Temperature
RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution

n : 134004
mini: 83.648
maxi: 2483.5



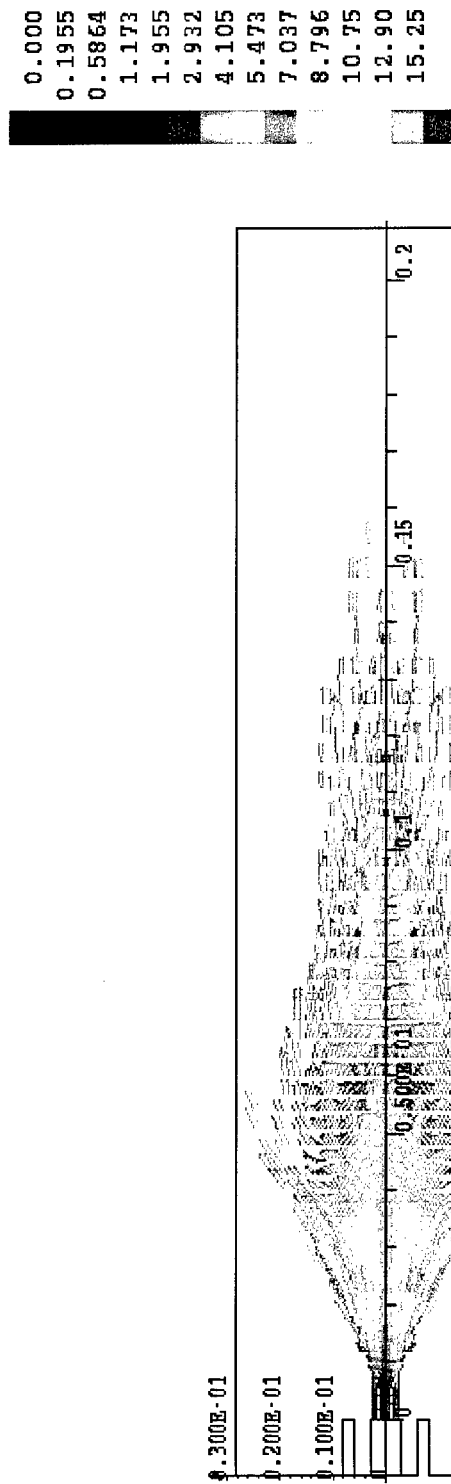
2nd RCM Workshop : RCM2 10 bars test case

The results

5

Velocity vectors of the dispersed phase
RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution

n : 134004
mini: 0.0000
maxi: 15.247

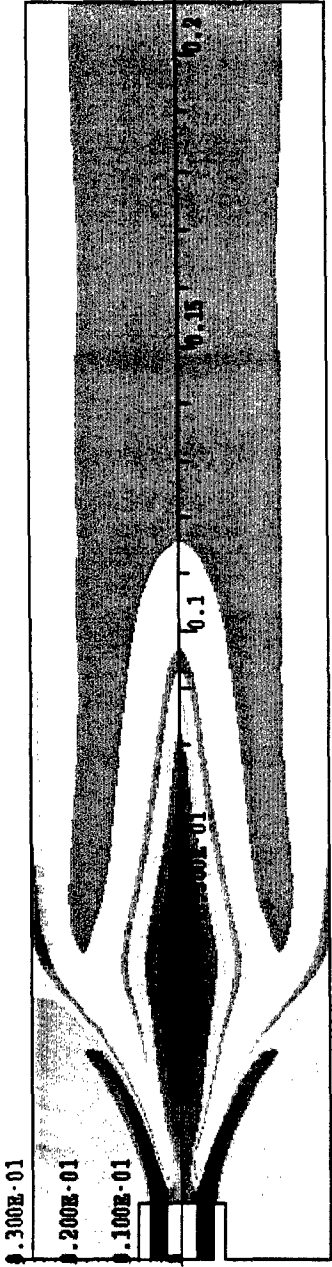
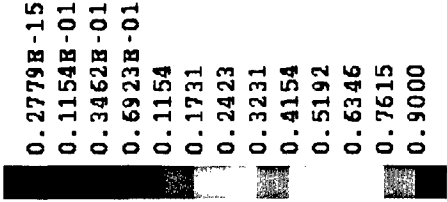


2nd RCM Workshop : RCM2 10 bars test case

The results

Massic fraction of H2O
RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution

n : 134004
mini: 2.18579E-16
maxi: 0.67382



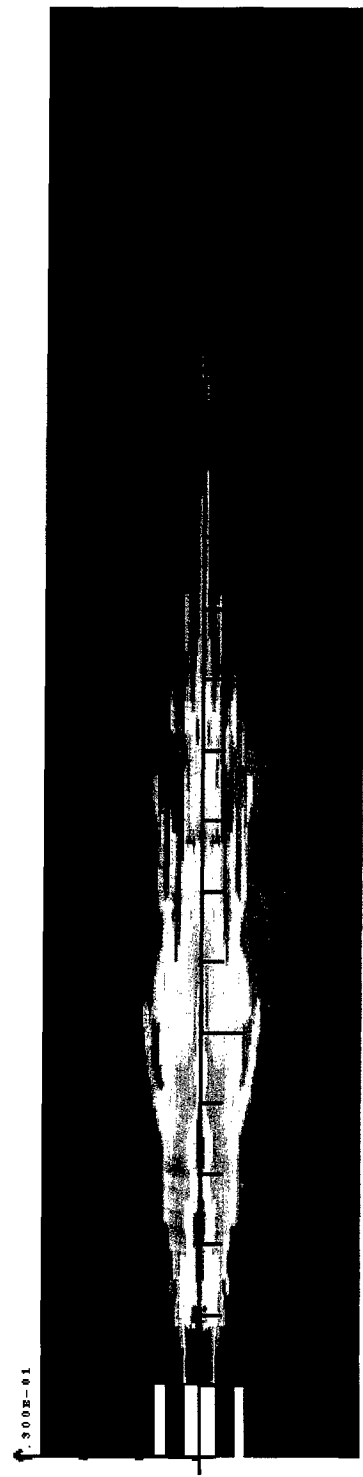
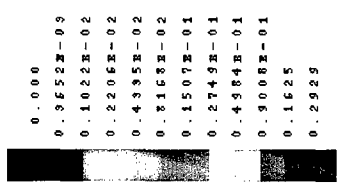
2nd RCM Workshop : RCM2 10 bars test case

The results

5

Volumic rate for the polydispersed phase
Test case Rosin Ramler V=10 m/s

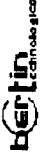
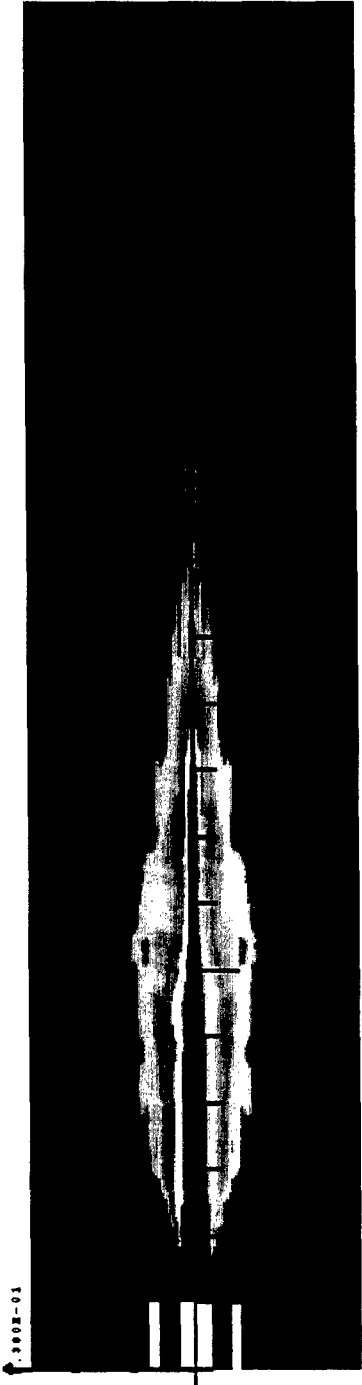
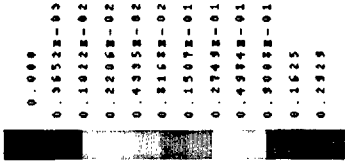
t : 0.0000
mini: 0.0000
maxi: 0.41039



2nd RCM Workshop : RCM2 10 bars test case

The results

Volumic rate for the polydispersed phase	
Test case	Rosin Ramler V-3 m/s
min:	0.0000
max:	4.3172

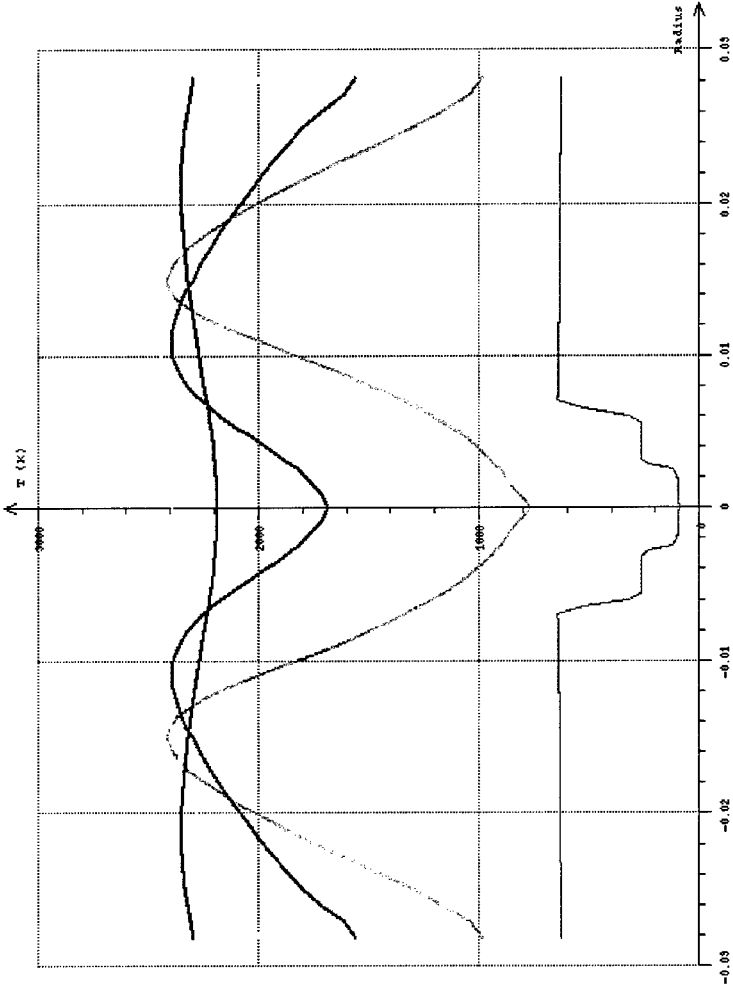


2nd RCM Workshop : RCM2 10 bars test case

The results

Temperature	θ :	0.0000
Test case	Rosin Ramler	$V=10$ m/s
	mini :	91.925
	maxi :	2459.5

$x = 0$ cm
$x = 5$ cm
$x = 10$ cm
$x = 20$ cm

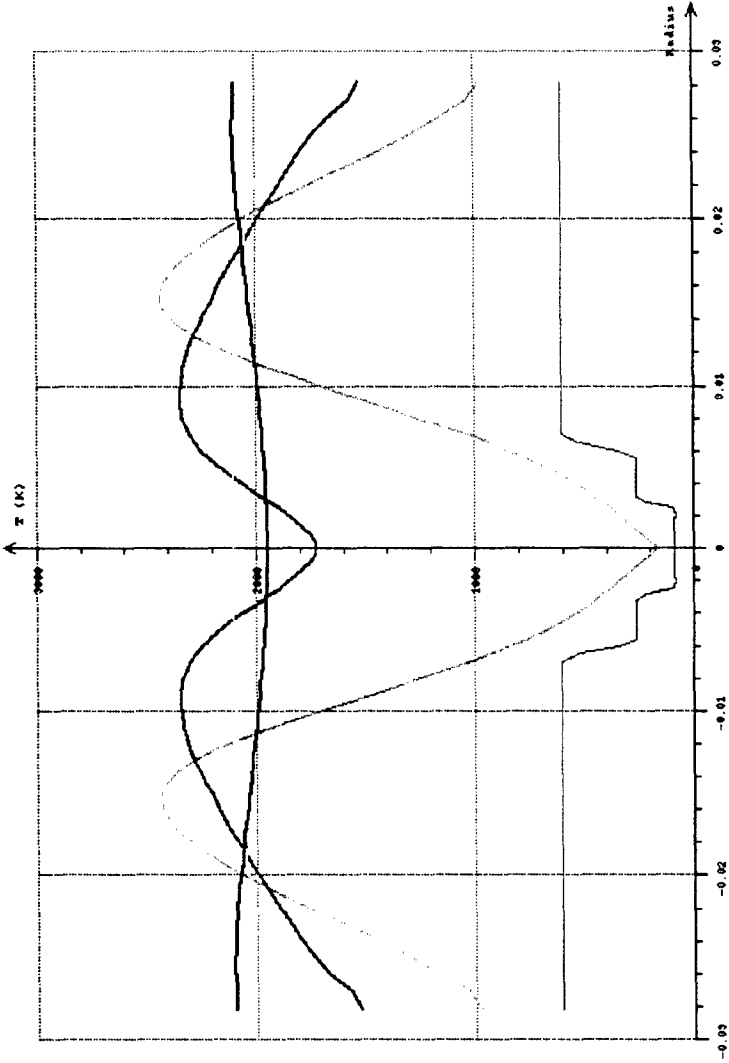


2nd RCM Workshop : RCM2 10 bars test case

The results

Temperature	0.0000
Test case	Rosin Ramler V=3 m/s
	85.648
	2483.5

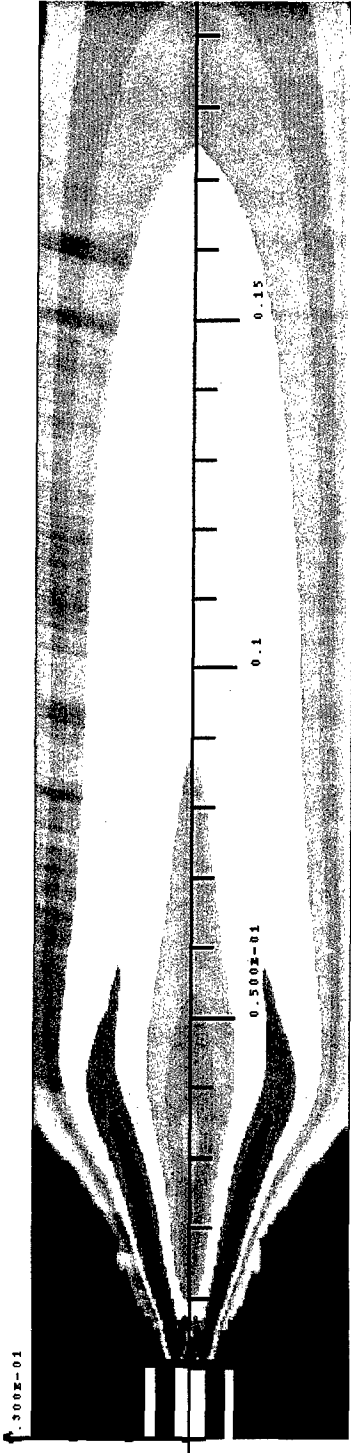
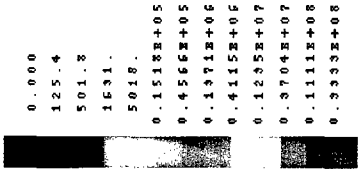
x = 0 cm
x = 10 cm
x = 20 cm



2nd RCM Workshop : RCM2 10 bars test case

The results

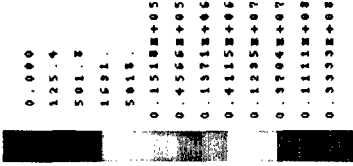
Production rate Te	t :	0.0000
Test case	Rosin Ramler	v=10 m/s
	mini:	-1.61311E-06
	max:	1.80042E+08



2nd RCM Workshop : RCM2 10 bars test case

The results

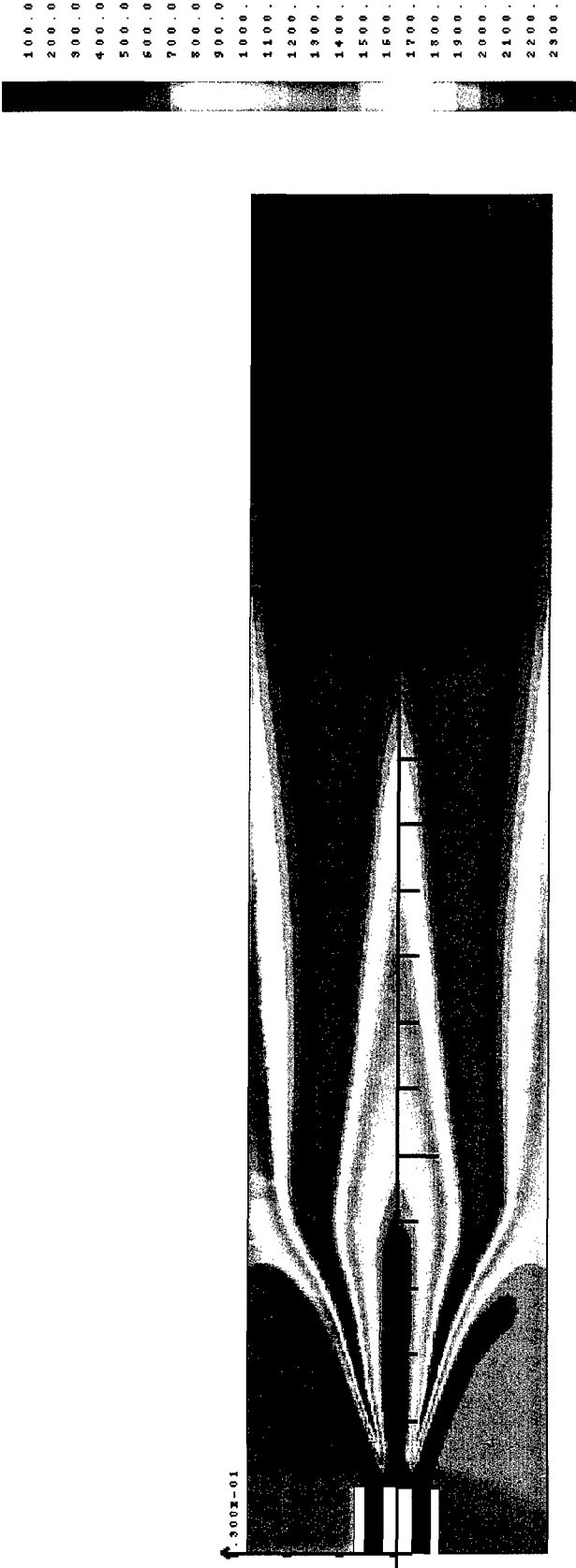
Production rate	Te
Test case	Rosin Ramler V-3 m/s
	mini -1.49109E-06
	maxi -1.41220E+08



2nd RCM Workshop : RCM2 10 bars test case

The results

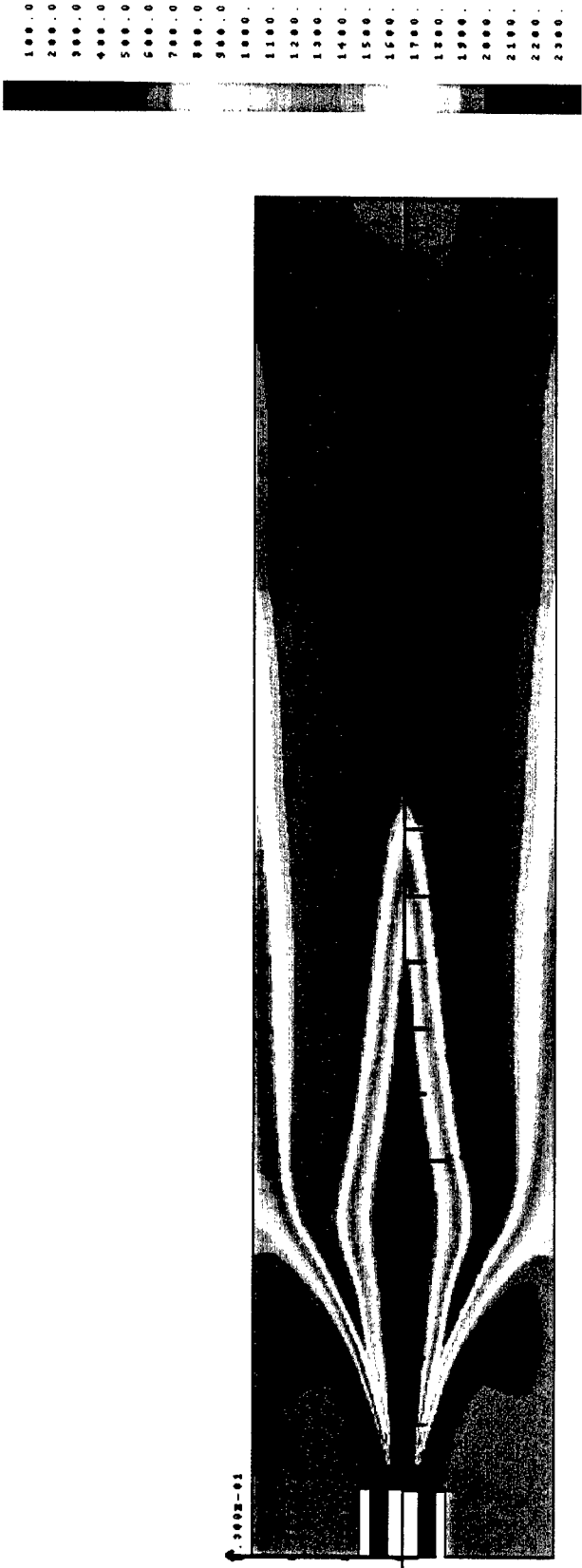
Temperature	b :	0.0000
Test case	Rosin Ramler	V=10 m/s
	mini :	91.925
	maxi :	2459.5



2nd RCM Workshop : RCM2 10 bars test case

The results

Temperature	V :	0.0000
Test case	Rosin Ramler	V=3 m/s
	min :	53.648
	max :	2483.5



2nd RCM Workshop : RCM2 10 bars test case

The conclusion

6

- ☐ The use of the most recent version of CPS has been quite straightforward
 - ☐ the recent developments to deal with high volumic rates areas appear to be quite robust and can still be enhanced with respect to evaporation
 - ☐ it would be very easy to introduce some very large "droplets" as it seems it appears during experiments
- ☐ Further developments must be done to be able to use the implicit solver
 - ☐ this mandatory to decrease the CPU cost which is very high
- ☐ The comparison with experimental results will allow to asses the quite "rough" injection strategy
 - ☐ at least it is conservative
- ☐ Good thermodynamic properties is essential for a good evaporation model