معهد قطر لبحوث البيئة والطاقة
Qatar Environment & Energy Research Institute

جامعة حمد بن خليفة
HAMAD BIN KHALIFA UNIVERSITY

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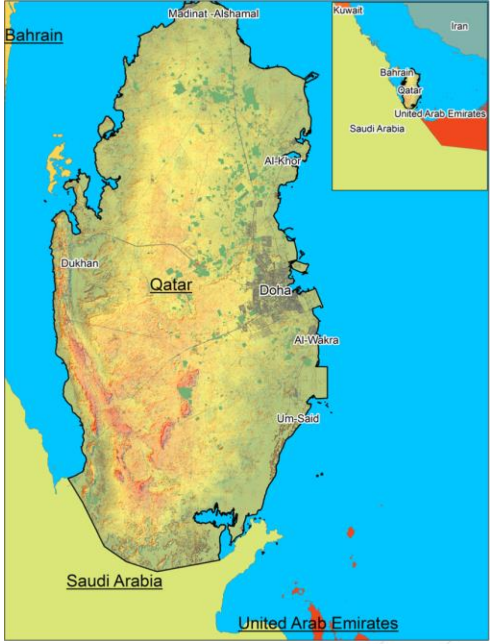
Laboratoire d'Hydrologie et de Géochimie de Strasbourg

On the efficiency of ELLAM for mass transport in fractured porous media: Application to Qatar's aquifer storage project

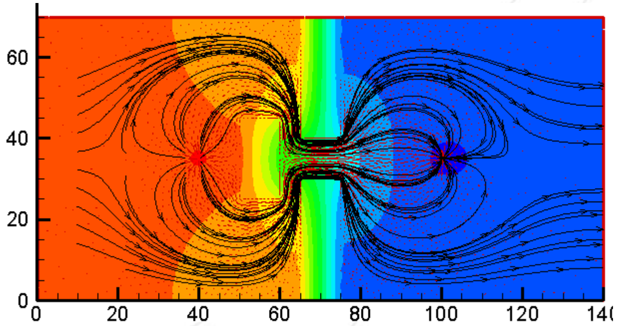
Fanilo Ramasomanana, Marwan Fahs, Husam M Baalousha, Nicolas Barth, Said Ahzi

Qatar is an arid country where aquifers, which are the only source of fresh natural groundwater, are over exploited.

This study contributes to the Aquifer Storage and Recovery (ASR) project by developing a numerical model for flow and transport in fractured porous media. The model is based on the combination of **MHFEM** and **ELLAM**.



Field measurements



Modeling

Experiments

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Mathematical model

Fluid flow is described by the combination of Darcy's law and the continuity equation

(1) $$S_s \frac{\partial h}{\partial t} + \nabla . \boldsymbol{q} = f_{ps}$$ Continuity equation

(2) $$\boldsymbol{q} = -\boldsymbol{K} \nabla h$$ Darcy's law

(3) $$S_s \frac{\partial h}{\partial t} - \nabla . (\boldsymbol{K} \nabla h) = f_{ps}$$ Diffusivity equation

Solute transport is described by the classical advection-dispersion differential equation

(4) $$\frac{\partial C}{\partial t} + \nabla . \left(\boldsymbol{u} C - \boldsymbol{D} \nabla C \right) = 0$$

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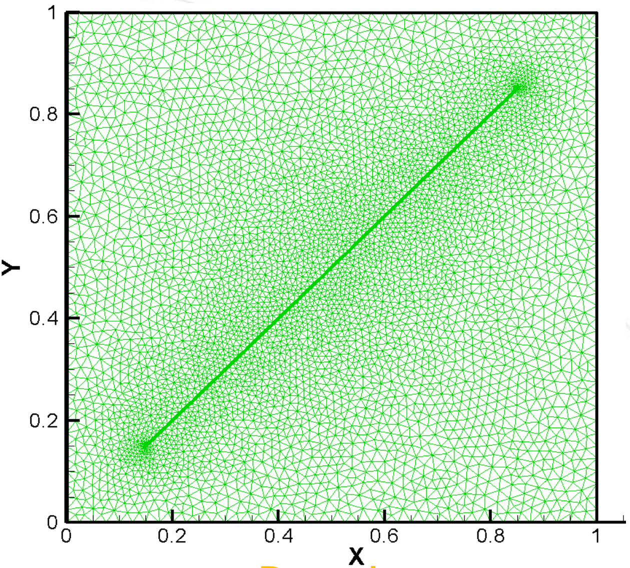
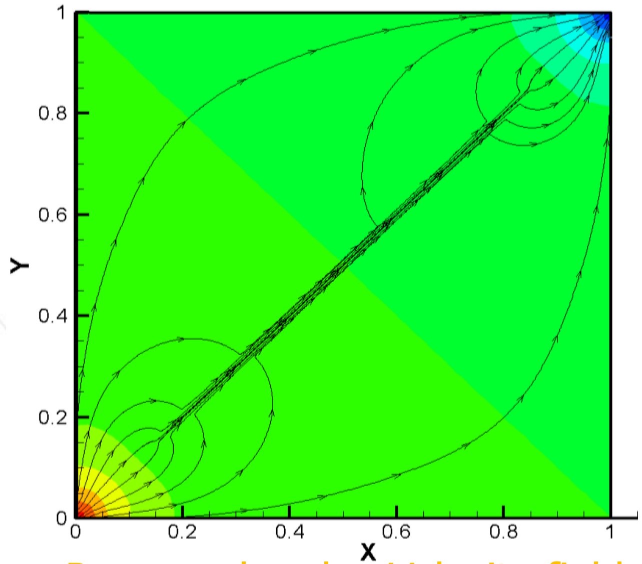
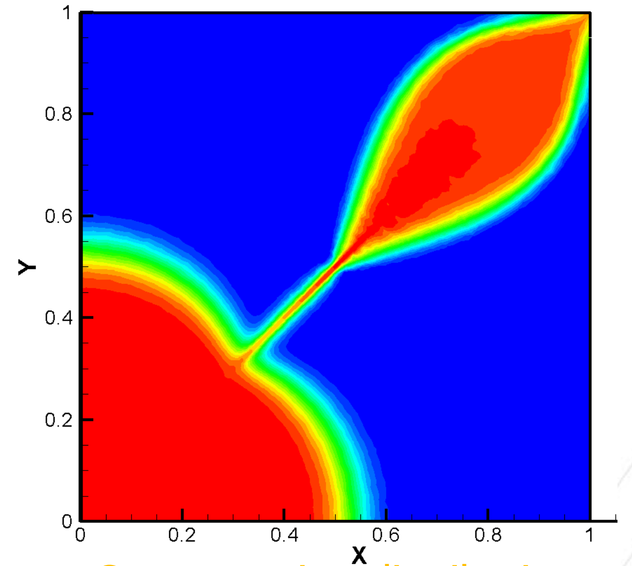


Domain



Pressure head + Velocity field



Concentration distribution

- *Porous matrix + fracture*
- *13000 elements*

MHFEM

- *Accurate approximation of velocities and pressures*
- *Continuity of velocities across interelement*

ELLAM

- *Advective part solved with Lagrangian scheme*
- *Dispersive part solved with Eulerian scheme*
- *Less numerical dispersion*
- *Use of large time step*

❑ Several fracture configuration are tested and compared with results obtained by Discontinuous Galerkin Method.

❑ We plan to use these scheme to validate future experiments + 3D Extension

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Thank You

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Abstract n°1965

On the efficiency of ELLAM for mass transport in fractured porous media: Application to Qatar's aquifer storage project

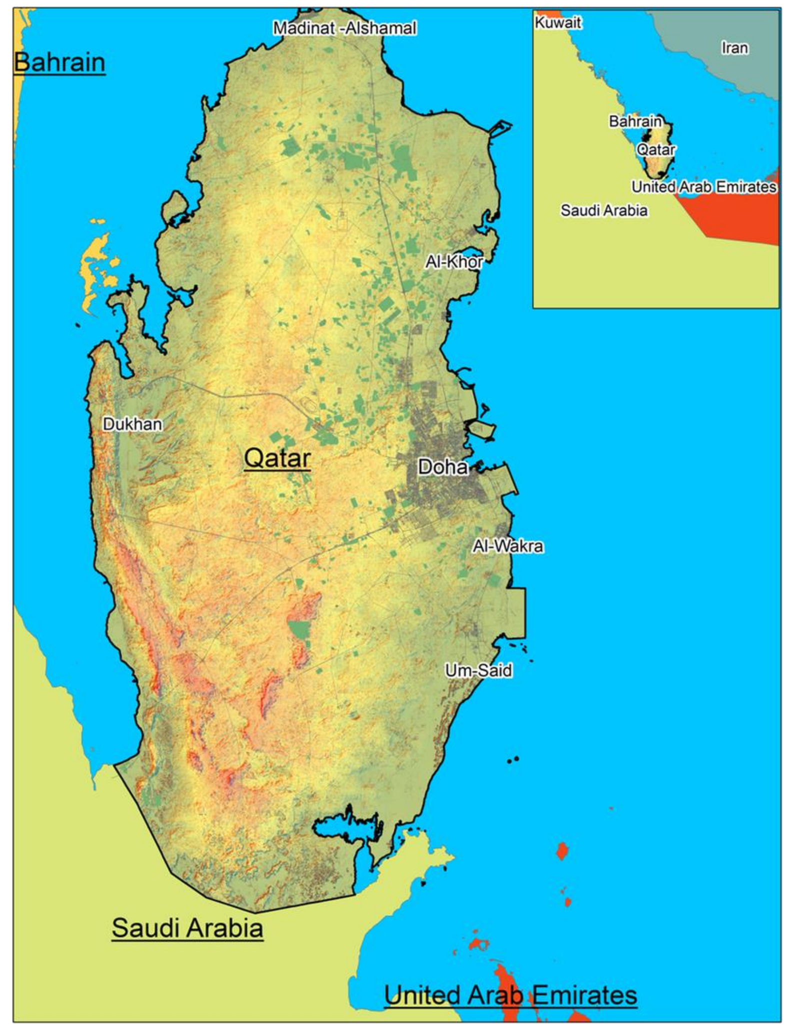
Fanilo Ramasomanana.[(1)*], Marwan Fahs.[(2)], Husam M Baalousha.[(1)], Nicolas Barth.[(1)], Said Ahzi.[(1)]

1

Water security is one of the main Grand Challenges aligned with Qatar's 2030 National Vision, which highlights the urgent need to have access to safe, high quality and sustainable water supply. The Aquifer Storage and Recovery (ASR) project aims at artificially storing water in the aquifer for future use. This study contributes to the ASR by developing an efficient and accurate numerical model for flow and transport in fractured porous media. The model is based on the combination of **M**ixed **H**ybrid **F**inite **E**lement **M**ethod (**MHFEM**) and the **E**ulerian **L**agrangian **L**ocalized **A**djoint **M**ethod (**ELLAM**) which can handle efficiently mass transfer in such porous media.

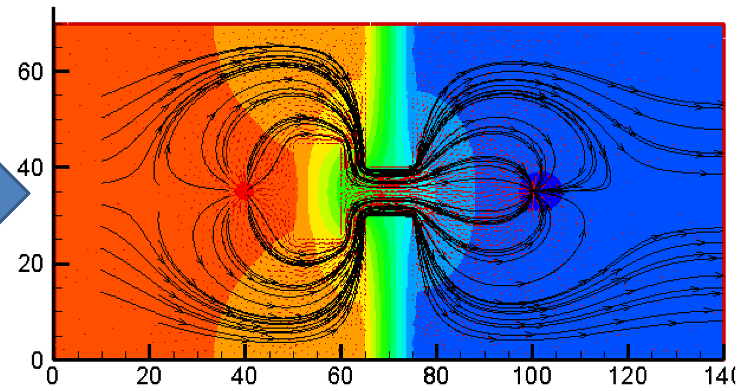
2

- It is important to understand the hydrogeology and the hydro-geochemistry of aquifers in Qatar to implement a successful aquifer recharge and recovery scheme.

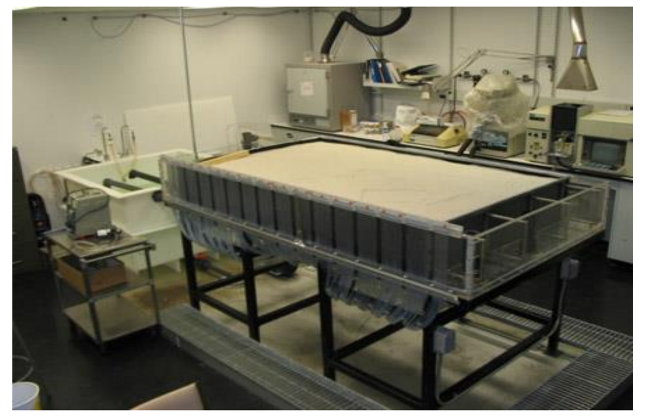


- The development of a robust and efficient numerical model which can handle flow and mass transfer in fractured media is one part of the work to achieve the ASR.

Field measurements



Modeling



Experiments

(1) Qatar Environment & Energy Research Institute, Hamad Bin Khalifa University, Qatar Foundation, Doha, Qatar
(2) Laboratoire d'Hydrologie et de Géochimie de Strasbourg – Université de Strasbourg/CNRS, Strasbourg, France
* framasomanana@qf.org.qa

3

- **Fluid flow** is described by the combination of Darcy's law and the continuity equation, and solved with the MHFEM

(1) $$S_s \frac{\partial h}{\partial t} + \nabla . \boldsymbol{q} = f_{ps}$$ Continuity equation

(2) $$\boldsymbol{q} = -\boldsymbol{K} \nabla h$$ Darcy's law

(3) $$S_s \frac{\partial h}{\partial t} - \nabla .(\boldsymbol{K} \nabla h) = f_{ps}$$ Diffusivity equation

$\boldsymbol{q}$ Darcy's velocity $[L.T^{-1}]$
h Pressure head [L]
$\boldsymbol{K}$ Permeability tensor $[L.T^{-1}]$
S_s Permeability tensor $[L.T^{-1}]$
f_{ps} Sink/source term $[T^{-1}]$

- **Solute transport** is described by the classical advection-dispersion differential equation and solved with the ELLAM

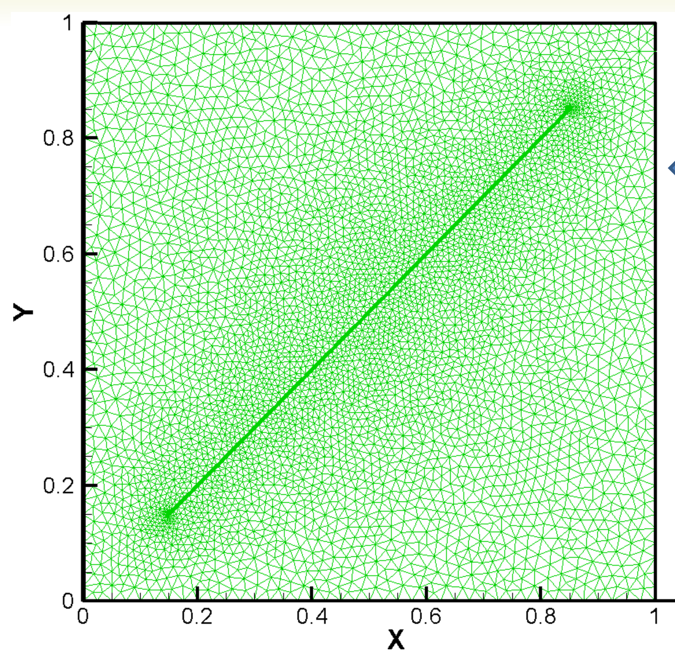
(4) $$\frac{\partial C}{\partial t} + \nabla . \left(\boldsymbol{u} C - \boldsymbol{D} \nabla C \right) = 0$$

$\boldsymbol{u}$ Fluid velocity vector $[L.T^{-1}]$
C Concentration $[M.L^{-3}]$
$\boldsymbol{D}$ Dispersion tensor $[L^2.T^{-1}]$

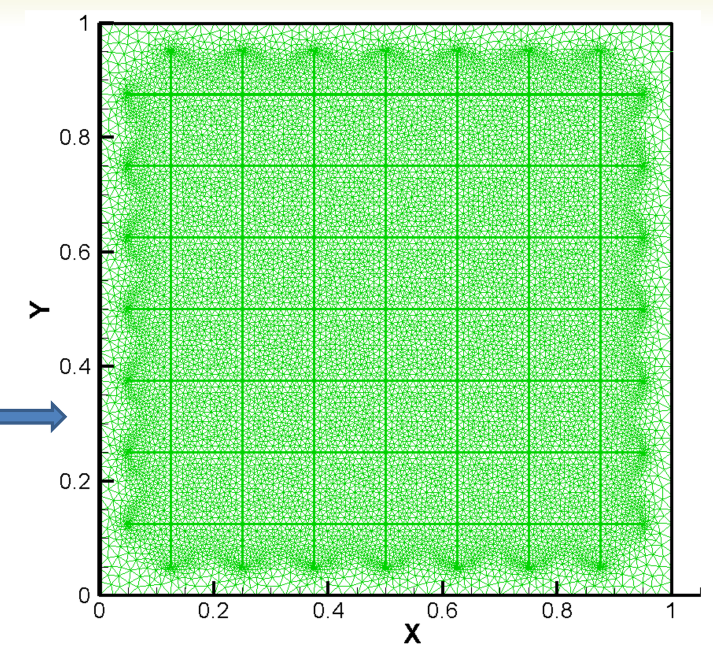
- The combination of MHFEM and ELLAM has been shown to be accurate and efficient for transport in heterogeneous media with sharp concentration fronts.

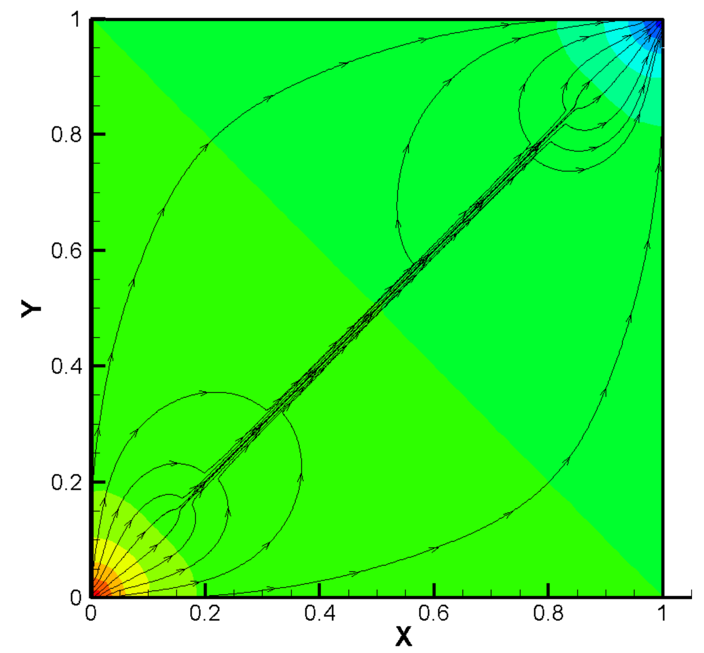
4

- In this work, the scheme is used for the first time to handle mass transfer in fractured porous media. Different fracture network configurations are tested.

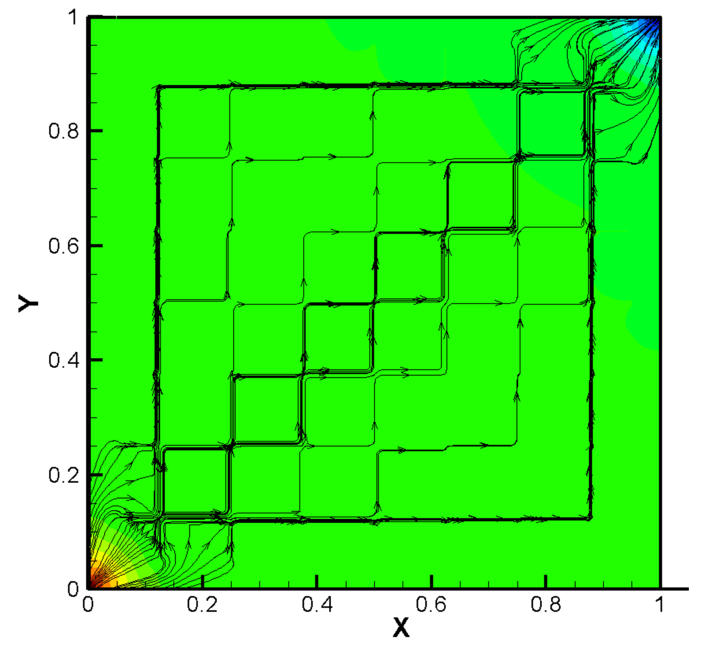


Single fracture & Sugar cube configuration



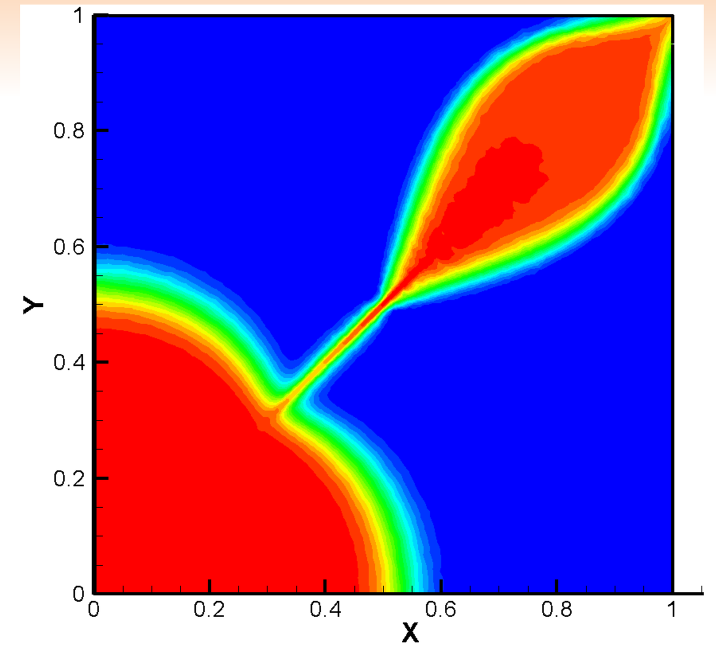


Pressure fields and Streamlines obtained with MHFEM

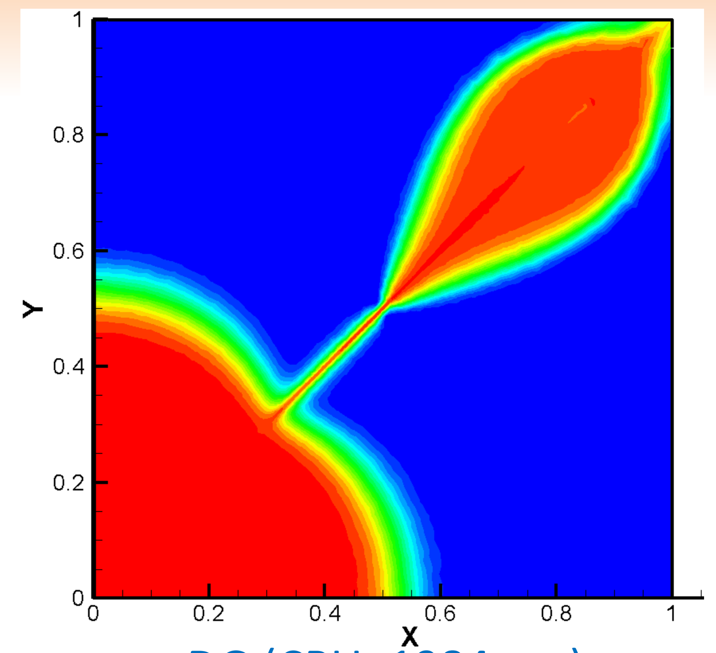


5

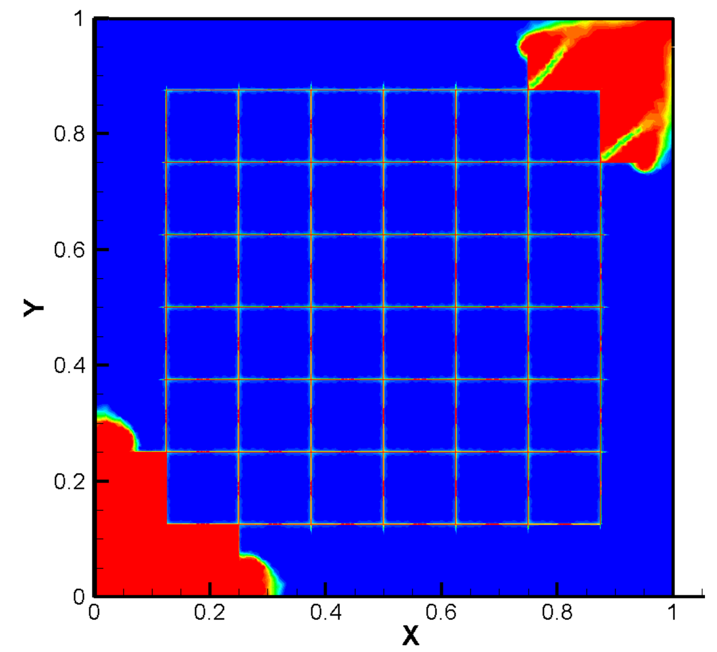
- The ELLAM model is compared to a Discontinuous Galerkin (DG) method.



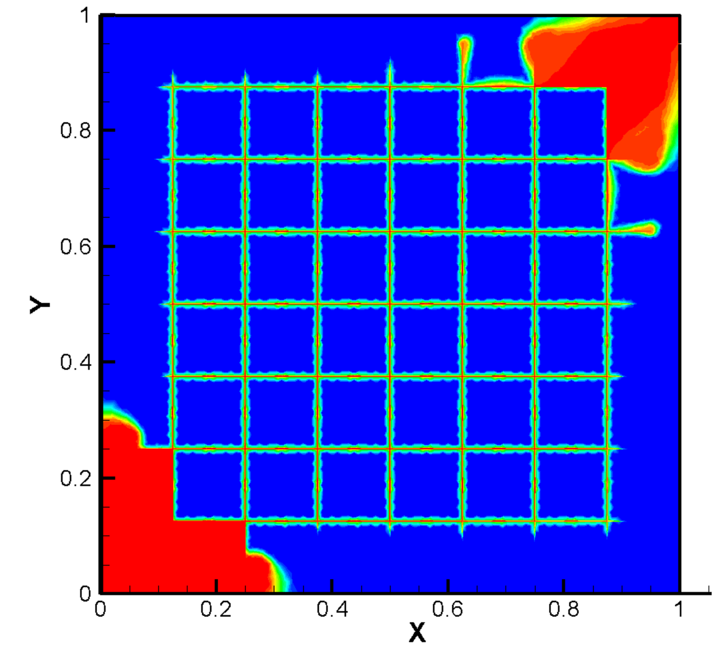
ELLAM (CPU=823 sec)



DG (CPU=1984 sec)



ELLAM (CPU=2103 sec)



DG (CPU=13913 sec)

6 Conclusions

- The ELLAM is used for the first time to simulate mass transfer in fractured porous media. The scheme can handle the high contrast velocity between the porous matrix and the fracture without introducing numerical diffusion.
- The ELLAM scheme remains much more efficient than the Discontinuous Galerkin finite element method.
- The use of ELLAM helps to overcome the limitations of computing resources.

7 References

[1] Hoteit, H., and A. Firoozabadi (2005), Multicomponent fluid flow by discontinuous Galerkin and mixed methods in unfractured and fractured media, Water Resour. Res., 41,W11412.

[2] Younes, A., P. Ackerer, and F. Lehmann (2006), A new efficient Eulerian-Lagrangian localized adjoint method for solving the advection-dispersion equation on unstructured meshes, Adv. Water Resour., 29, 1056–1074.

[3] Ramasomanana, F., and A. Younes (2011), Efficiency of the Eulerian-Lagrangian localized adjoint method for solving advection-dispersion equation on highly heterogeneous media, Int. J. Numer. Methods Fluids, 69, 639–652.