MODELLING OF ATMOSPHERIC FLOW AND DISPERSION IN THE WAKE OF A CYLINDRICAL OBSTACLE

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Aim of the paper

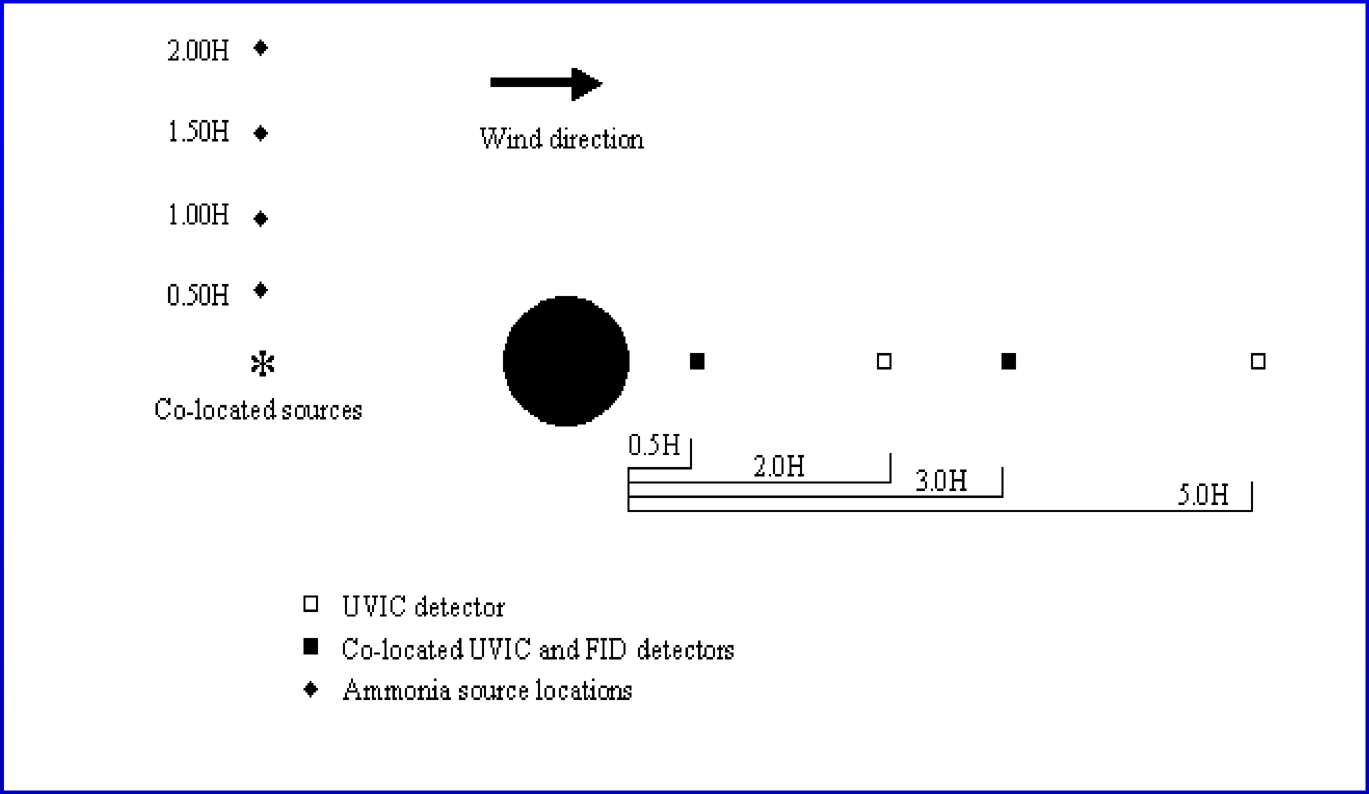
- Computational study of the interaction of continuous plumes released from point sources with buildings
  - short-range dispersion of atmospheric pollutants in built-up areas
  - Simple, isolated structures: main characteristics of flow and dispersion
- Present case: Cylindrical obstacle ("building")
  - Previously studied case: "Atmospheric dispersion in the presence of a three-dimensional cubical obstacle: Modelling of mean concentration and concentration fluctuations", by Mavroidis, Andronopoulos, Bartzis, Griffiths, *Atmospheric Environment* **41** (2007), 2740-2756

Tools, data, methods

- CFD code ADREA-HF
  - Mean concentrations, concentration fluctuations
- Data from field experiments
  - "Field and wind tunnel investigations of plume dispersion around single surface obstacles", by Mavroidis, Griffiths, Hall, *Atmospheric Environment* **37** (2003) 2903-2918
- Comparisons of calculated with experimental results / model performance
- Study of computed dispersion patterns
- Comparisons between cylindrical and cubical obstacles

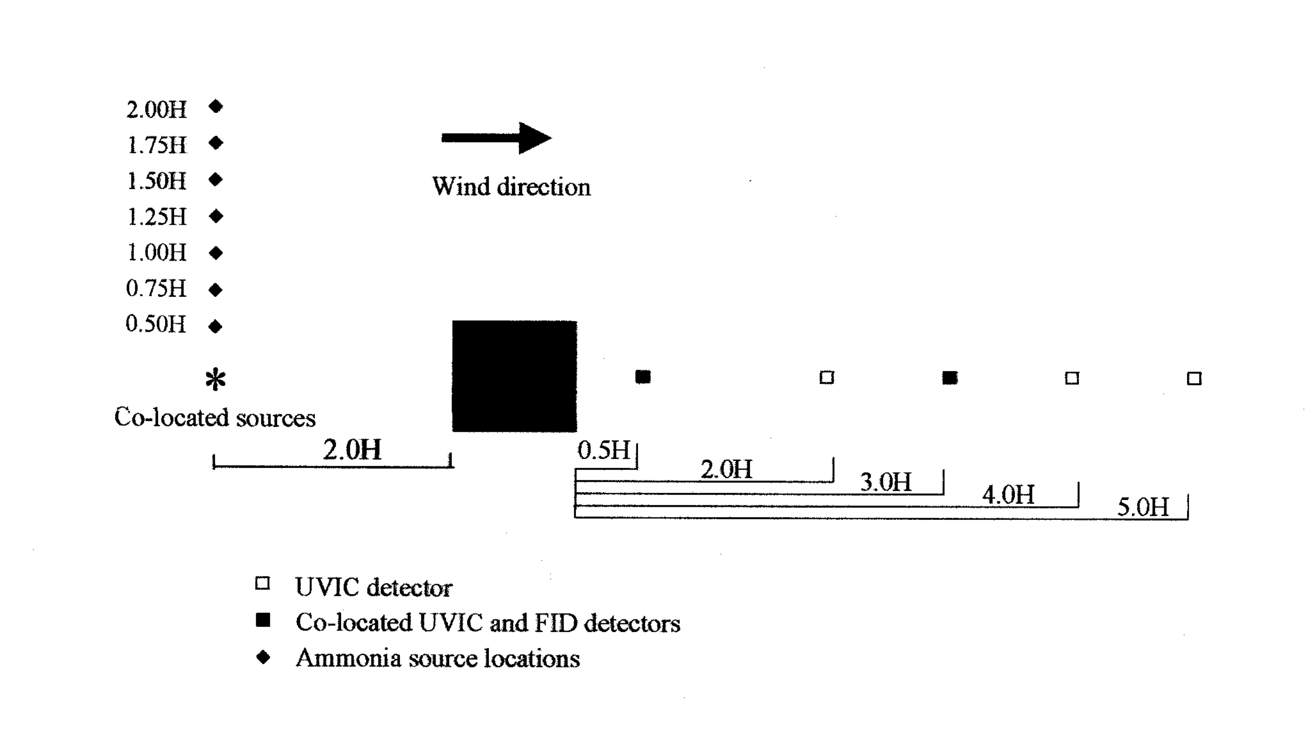
Experimental set up: cylinder

- Dual source:
  - Ammonia
  - Propane
- Ammonia source displaced laterally
- Height and diameter of cylinder H=1.15m
- Source and detector height: H/2
- Atmospheric stability: D (neutral)
- Wind speed: 2.6 – 4.5 m/s

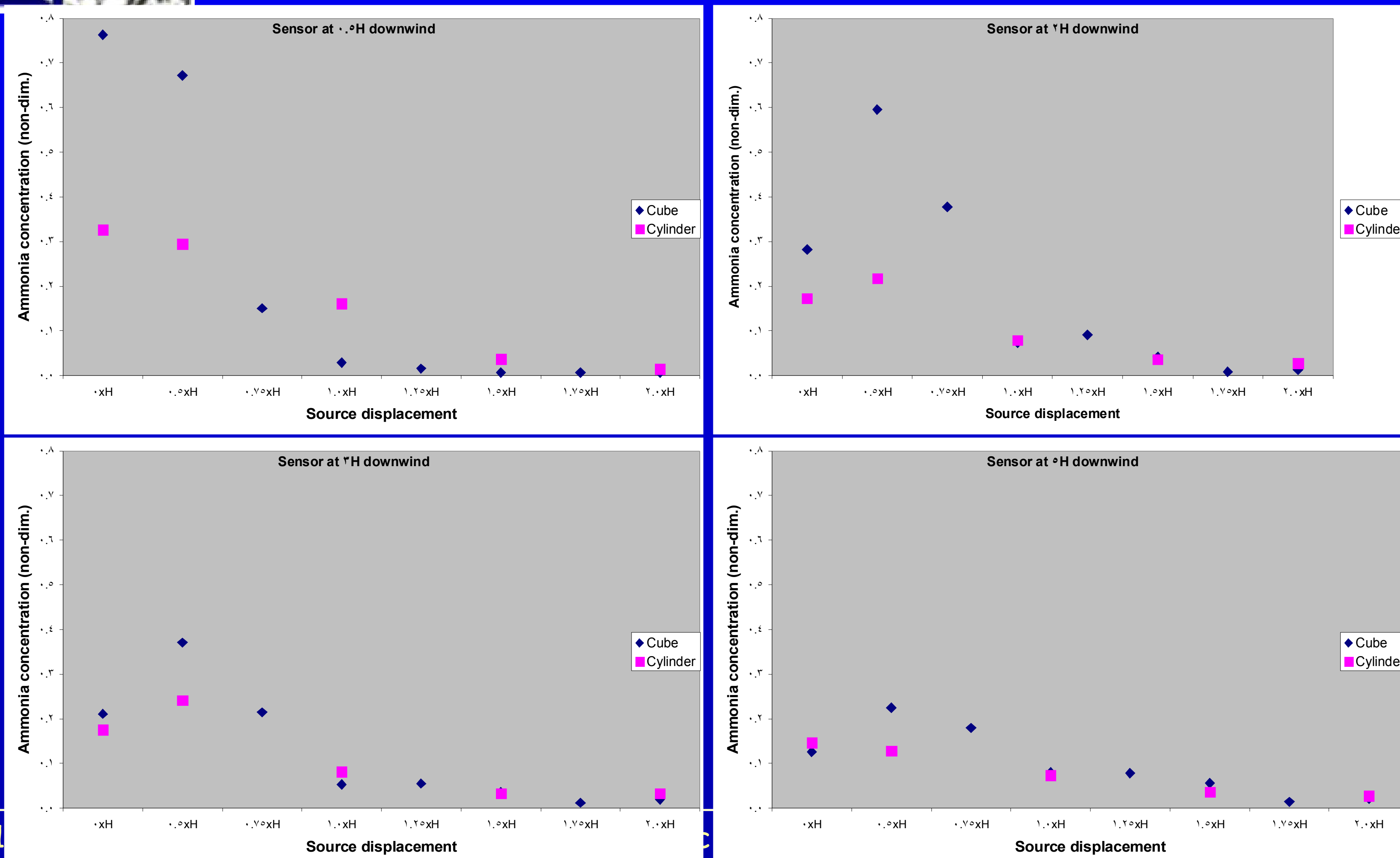


Experimental set up: cube

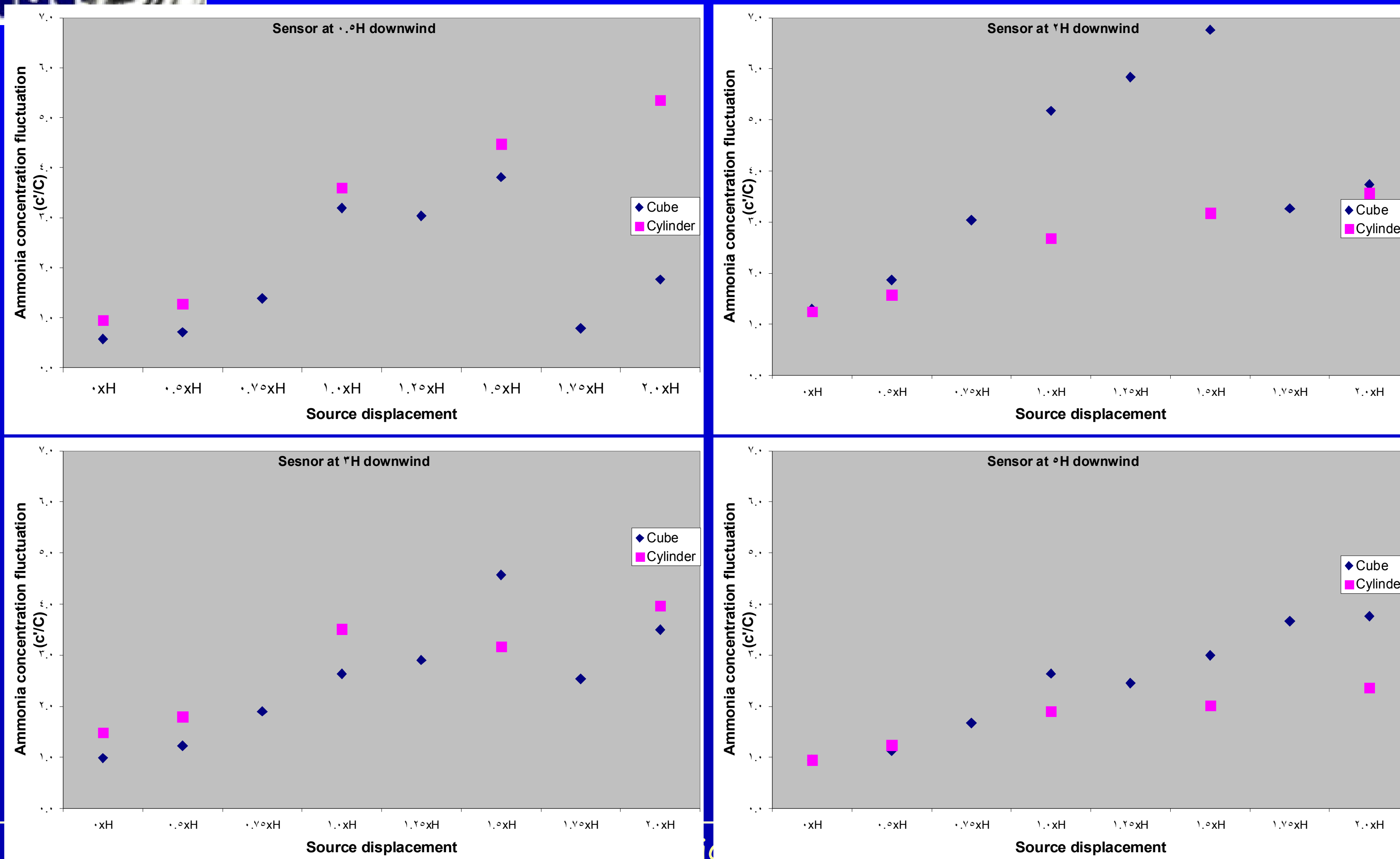
- Dual source:
  - Ammonia
  - Propane
- Ammonia source displaced laterally
- Height and diameter of cylinder H=1.15m
- Source and detector height: H/2
- Atmospheric stability: D (neutral)
- Wind speed: 4.7 – 6.3 m/s



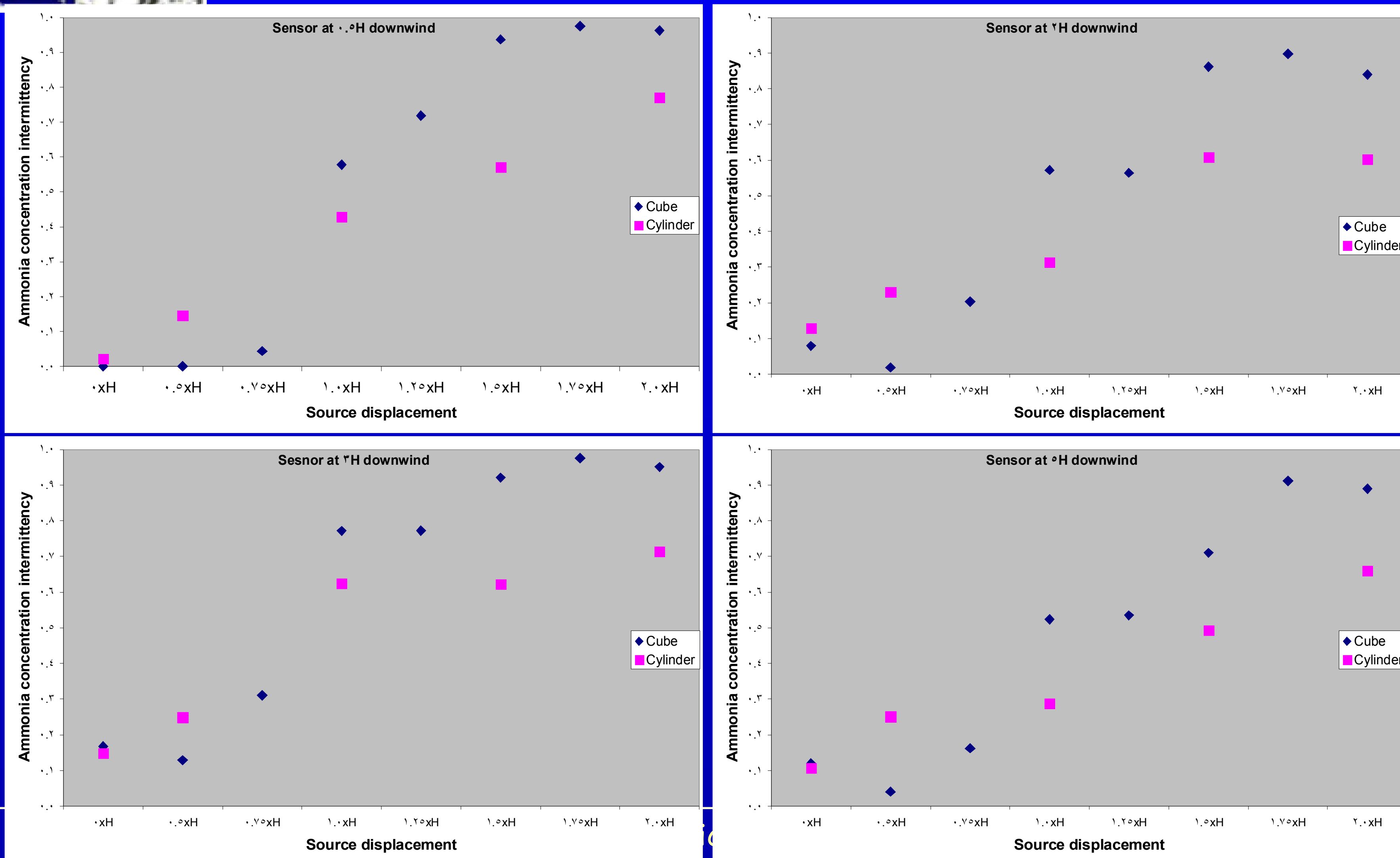
Experimental results: ammonia concentrations



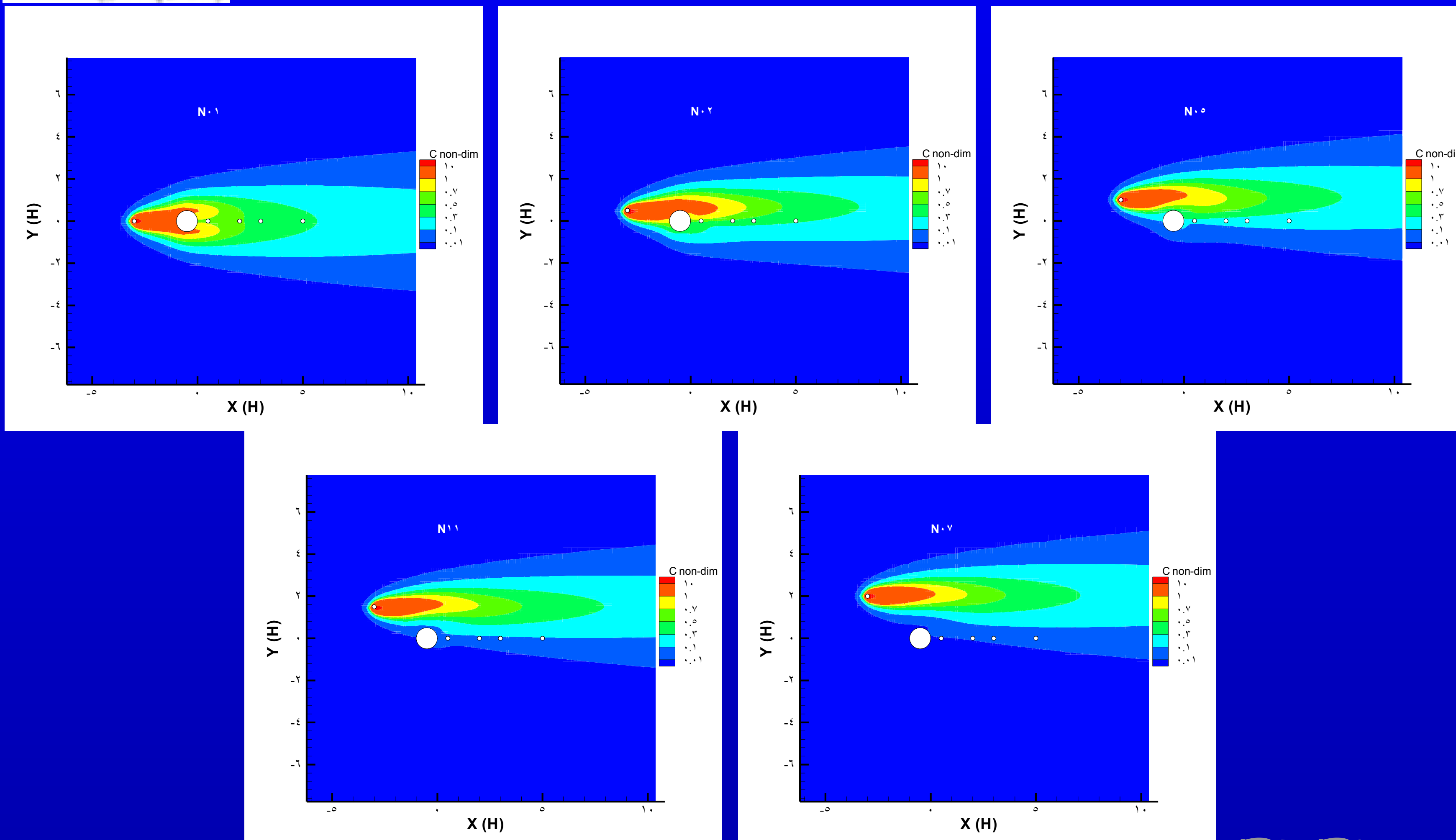
Experimental results: ammonia concentration fluctuations



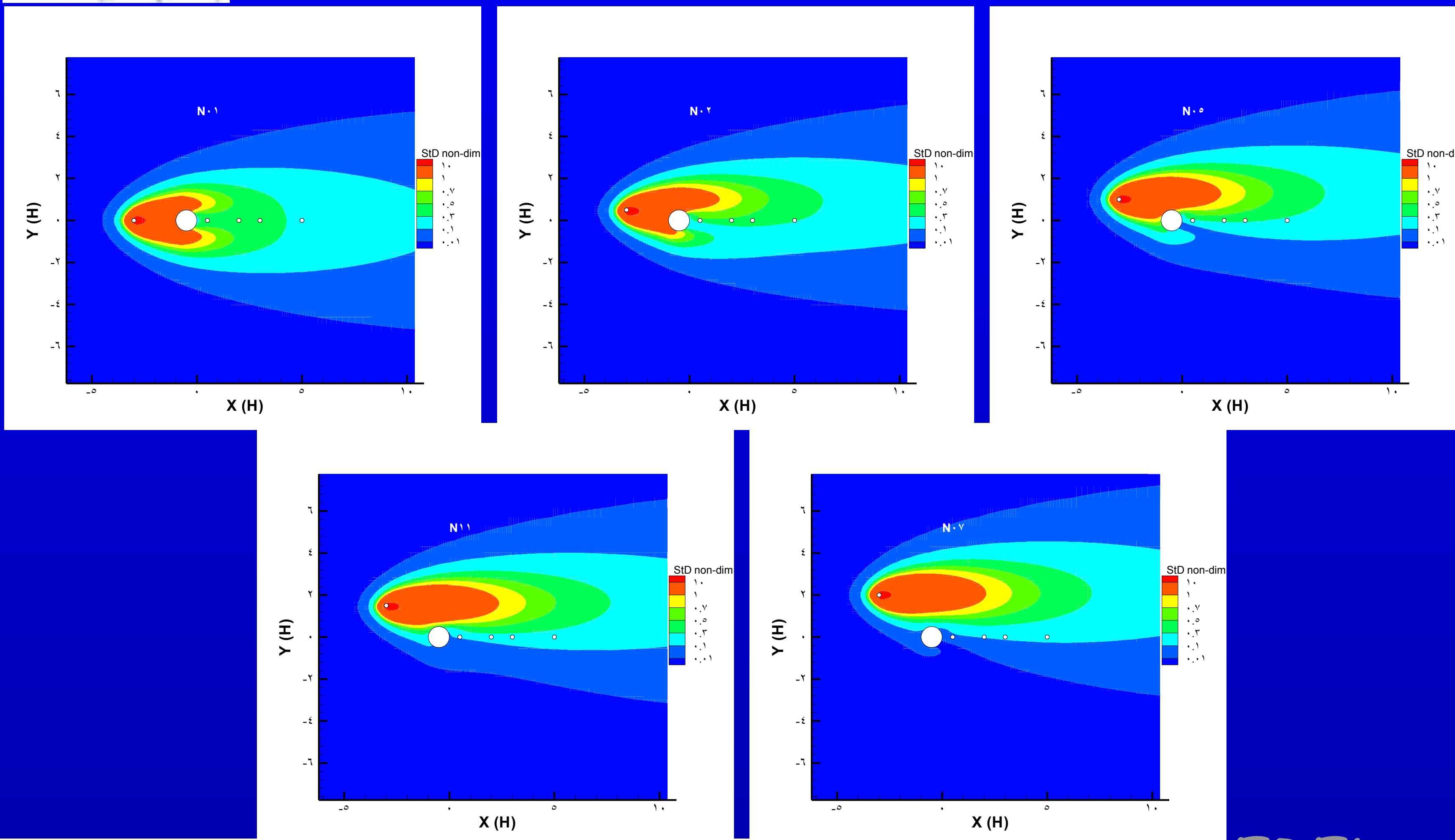
Experimental results: ammonia concentration intermittency



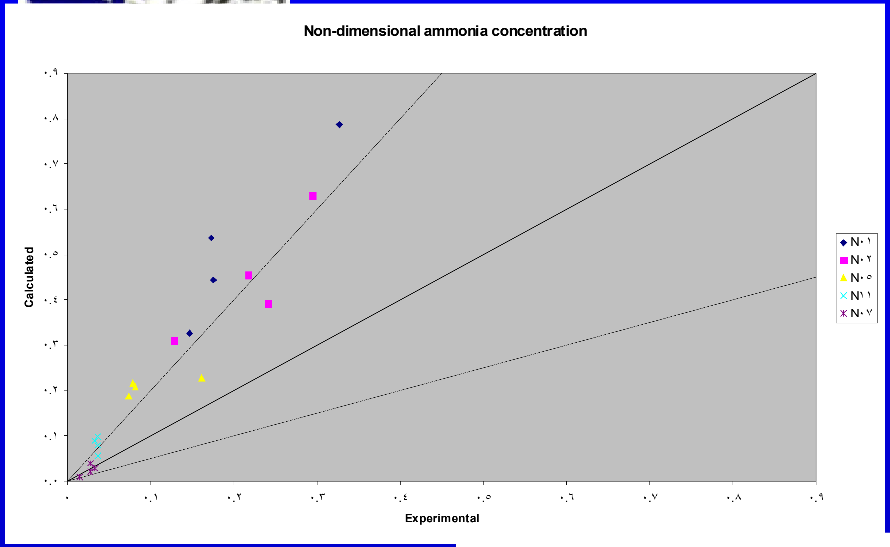
Computational results: non-dimensional mean concentration

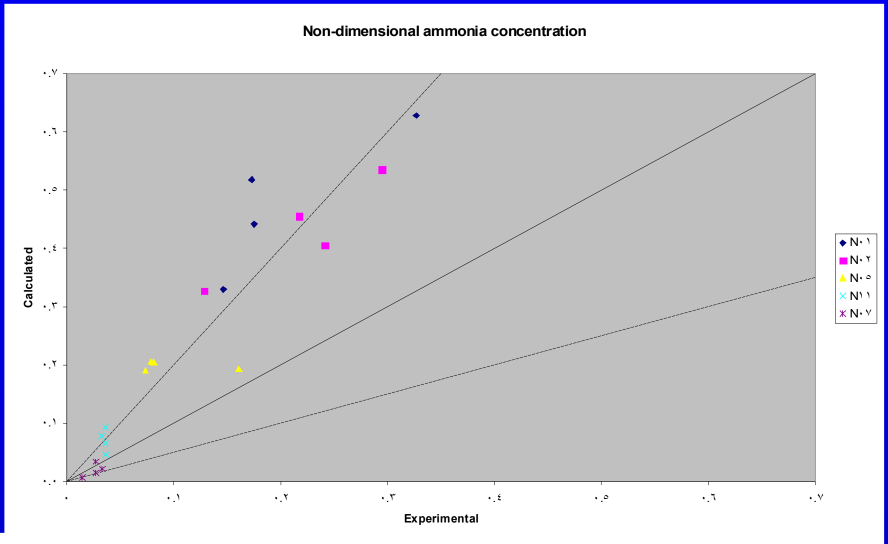


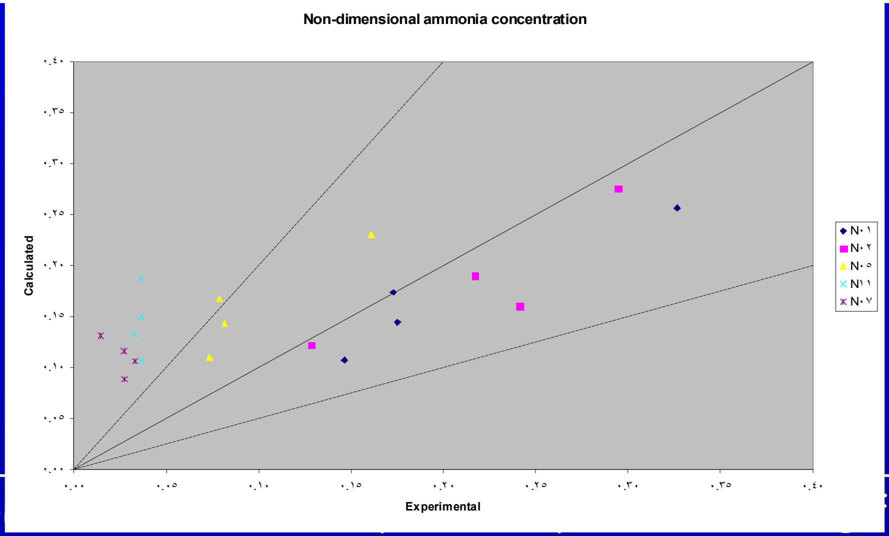
Computational results: non-dimensional concentration StD



Model evaluation: turbulence closure schemes – *k-l* (1), *k-ε*, *k-l* (2)







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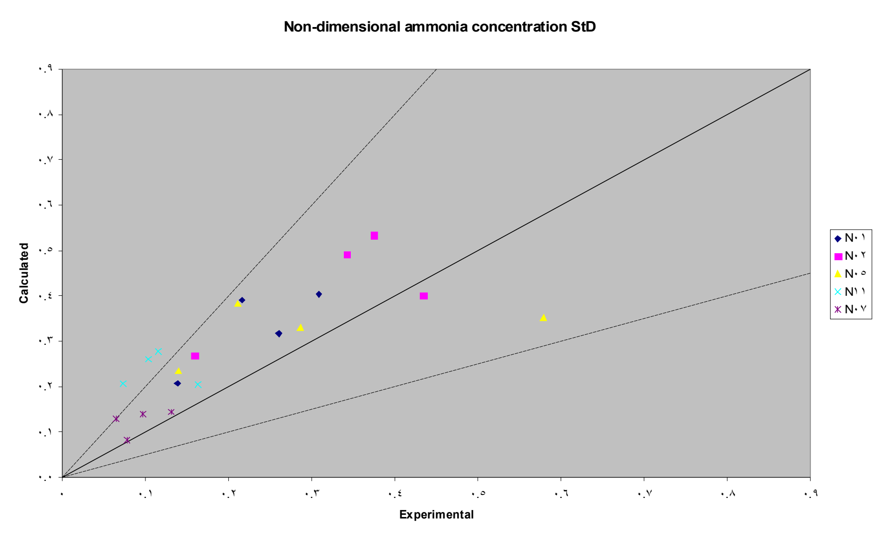

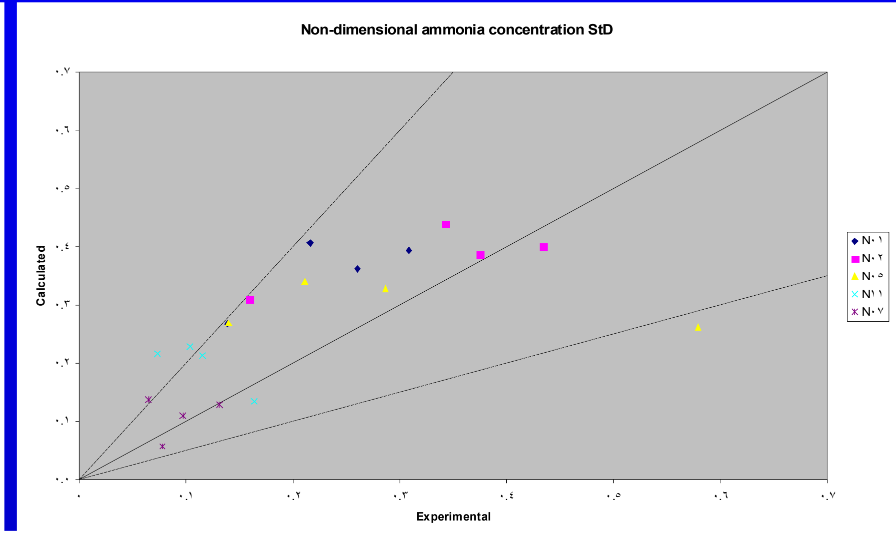

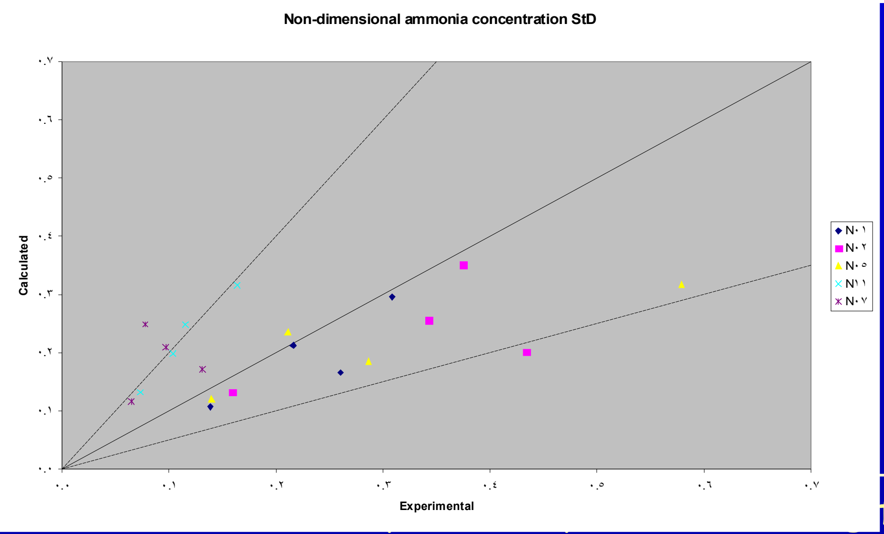

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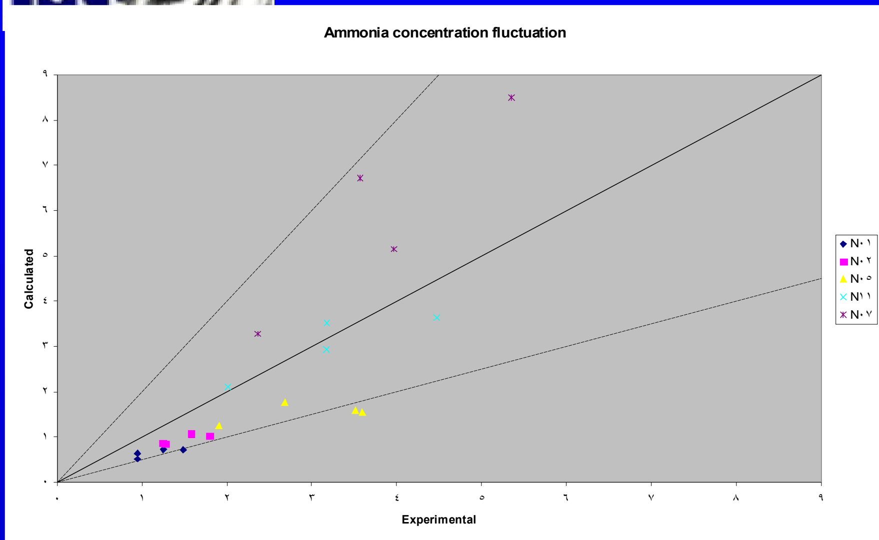
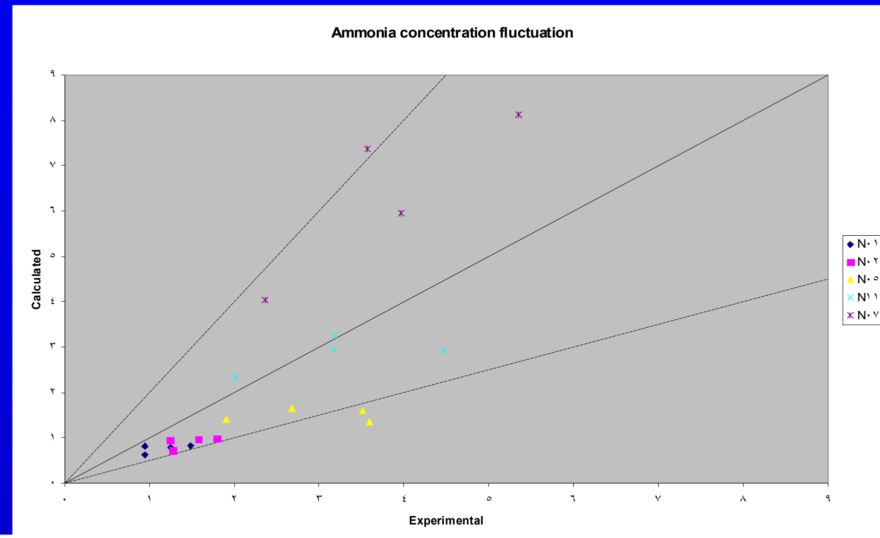
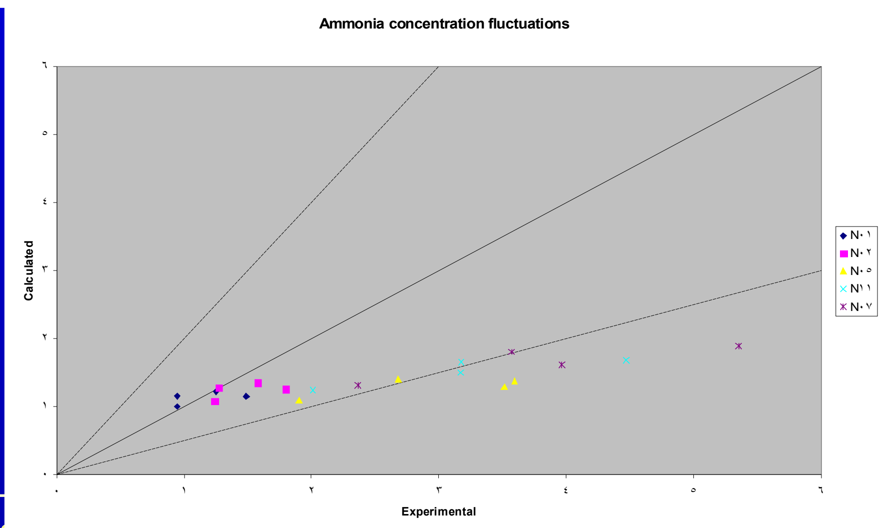






Model evaluation : turbulence closure schemes – *k-l* (1), *k-l* (2), *k-ε*

Propane Concentration

	Experimental		Calculated *k-l* (١)		Calculated *k-ε*		Calculated *k-l* (٢)	
	٠.٥H	٣.٠H	٠.٥H	٣.٠H	٠.٥H	٣.٠H	٠.٥H	٣.٠H
N٠١	٠.٤٢٣	٠.٢٣٨	٠.٧٨٨	٠.٤٤٥	٠.٦٢٩	٠.٤٤٢	٠.٢٦٢	٠.١٤٧
N٠٢	٠.٣١٩	٠.١٧١	٠.٨٠٦	٠.٤٦٣	٠.٦٦٤	٠.٤٨١	٠.٢٩٥	٠.١٦٨
N٠٥	٠.٢٨٨	٠.١٧٥	٠.٧٩٠	٠.٤٥١	٠.٦٤٢	٠.٤٥٩	٠.٢٨٠	٠.١٥٨
N١١	٠.٣٣٨	٠.٢٣٨	٠.٨٠٥	٠.٤٦١	٠.٦٦١	٠.٤٧٨	٠.٢٨٨	٠.١٦٤
N٠٧	٠.٢٠٤	٠.١٢٢	٠.٧٨٧	٠.٤٤٩	٠.٦٣٦	٠.٤٥٣	٠.٢٧٦	٠.١٥٦
Average	٠.٣١٤	٠.١٨٩	٠.٧٩٥	٠.٤٥٤	٠.٦٤٦	٠.٤٦٢	٠.٢٨٠	٠.١٥٨
Calc/Exper			٢.٥٣	٢.٤٠	٢.٠٦	٢.٤٥	٠.٨٩	٠.٨٤

Propane Concentration StD

	Experimental		Calculated *k-l* (١)		Calculated *k-ε*		Calculated *k-l* (٢)	
	٠.٥H	٣.٠H	٠.٥H	٣.٠H	٠.٥H	٣.٠H	٠.٥H	٣.٠H
N٠١	٠.٥٣٧	٠.٢٧٨	١.٠٤٤	٠.٨٢٠	١.٠١٧	٠.٩٣٥	٠.٧٦٥	٠.٤٢٥
N٠٢	٠.٤٧٨	٠.٢٣٥	١.٢١٥	٠.٩٥٩	٠.٩٧٢	٠.٩٧٧	٠.٩٠٨	٠.٥١٢
N٠٥	٠.٤١٦	٠.٢٣٦	١.١٤١	٠.٨٩٧	٠.٩٨٧	٠.٩٦٦	٠.٨٤٥	٠.٤٧٥
N١١	٠.٣٧٢	٠.٢٧١	١.٢١٠	٠.٩٥٥	٠.٩٧٩	٠.٩٨٣	٠.٨٩٩	٠.٥١٠
N٠٧	٠.٣٣٩	٠.١٩٩	١.١٢٢	٠.٨٨١	٠.٩٩٣	٠.٩٦١	٠.٨٢٩	٠.٤٦٥
Average	٠.٤٢٩	٠.٢٤٤	١.١٤٦	٠.٩٠٢	٠.٩٨٩	٠.٩٦٤	٠.٨٤٩	٠.٤٧٨
Calc/Exper			٢.٦٧	٣.٧٠	٢.٣١	٣.٩٦	١.٩٨	١.٩٦

Model evaluation: comparison between cube and cylinder cases

Average propane concentrations for CUBE

	Experimental	Calculated, *k-l* (١)	Ratio	Calculated, *k-ε*	Ratio
٠.٥H	٠.٧٣٩	٠.٨١٦	١.١٠٣	٠.٨٠٩	١.٠٩٤
٣.٠H	٠.٢٤٦	٠.٤٣٨	١.٧٧٧	٠.٤٩١	١.٩٩٣

Average propane concentrations for CYLINDER

	Experimental	Calculated, *k-l* (١)	Ratio	Calculated, *k-ε*	Ratio
٠.٥H	٠.٣١٤	٠.٧٩٥	٢.٥٢٩	٠.٦٤٦	٢.٠٥٦
٣.٠H	٠.١٨٩	٠.٤٥٤	٢.٤٠٢	٠.٤٦٢	٢.٤٤٨

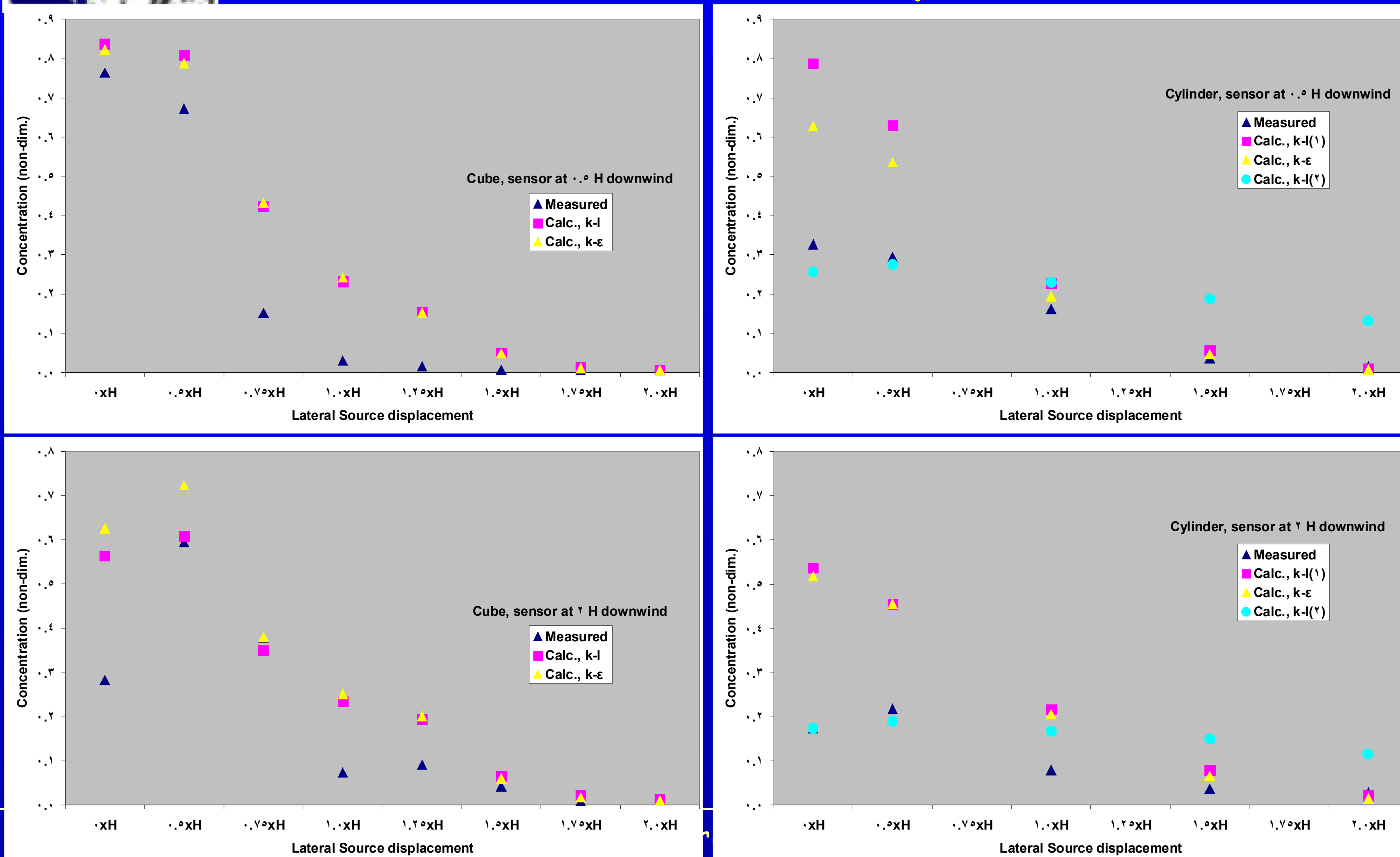
Average propane concentration StD for CUBE

	Experimental	Calculated, *k-l* (١)	Ratio	Calculated, *k-ε*	Ratio
٠.٥H	٠.٥٠٩	٠.٤٨٩	٠.٩٦٠	٠.٣٦٧	٠.٧٢١
٣.٠H	٠.٣٢٢	٠.٤٠٥	١.٢٥٦	٠.٣٥٠	١.٠٨٥

Average propane concentration StD for CYLINDER

	Experimental	Calculated, *k-l* (١)	Ratio	Calculated, *k-ε*	Ratio
٠.٥H	٠.٤٢٩	١.١٤٦	٢.٦٧٥	٠.٩٨٩	٢.٣٠٨
٣.٠H	٠.٢٤٤	٠.٩٠٢	٣.٧٠٣	٠.٩٦٤	٣.٩٥٧

Model evaluation: comparison between cube and cylinder cases



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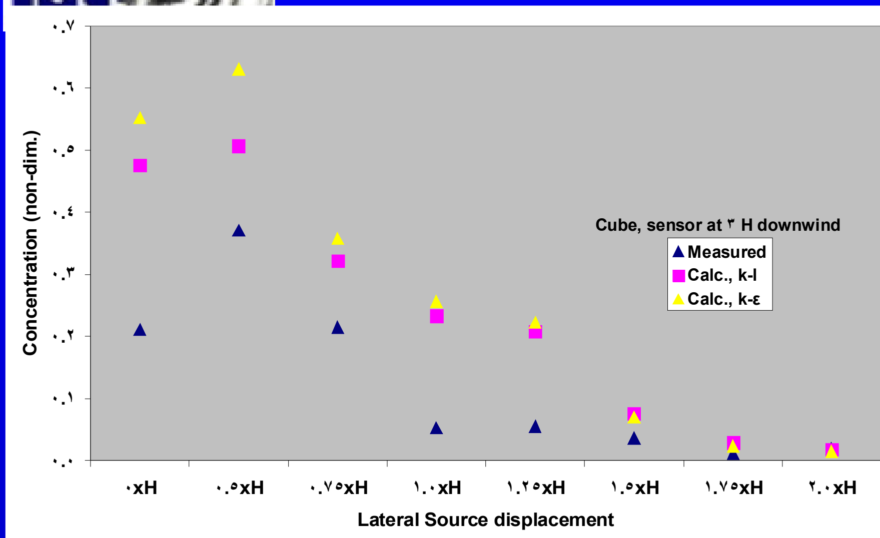

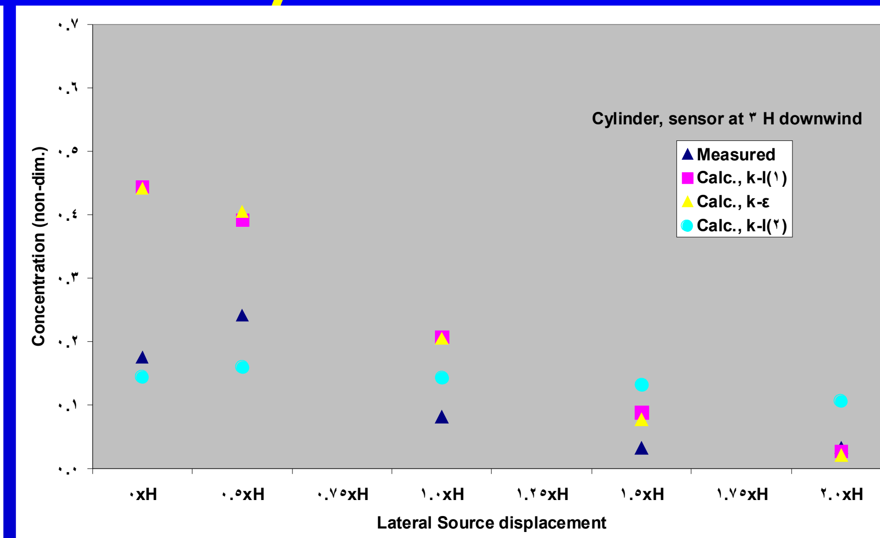

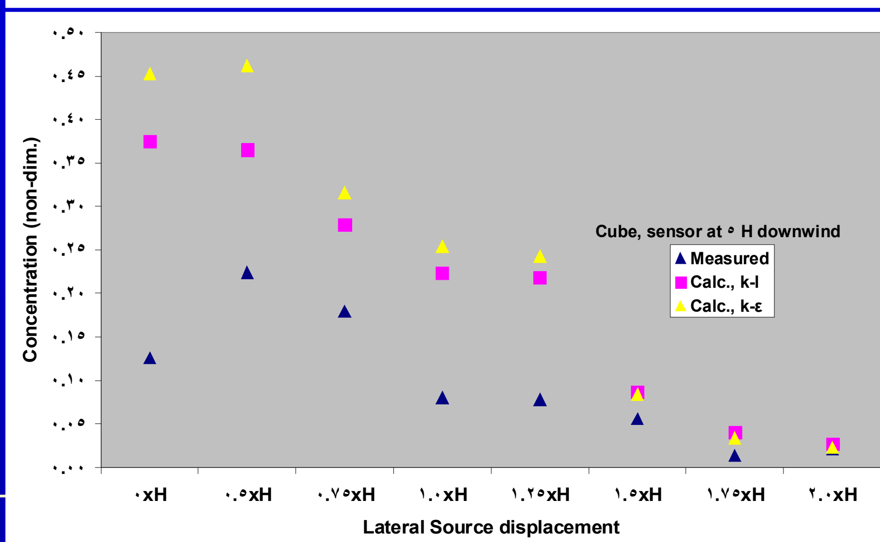

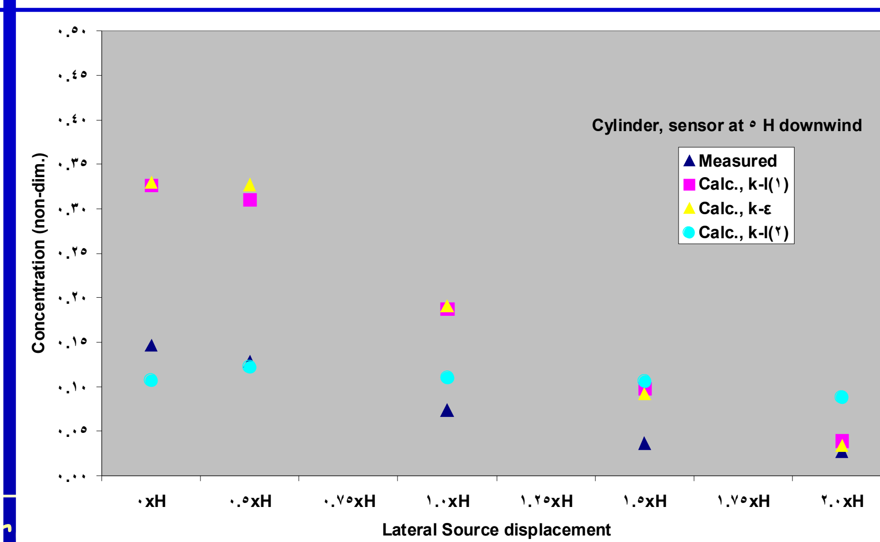

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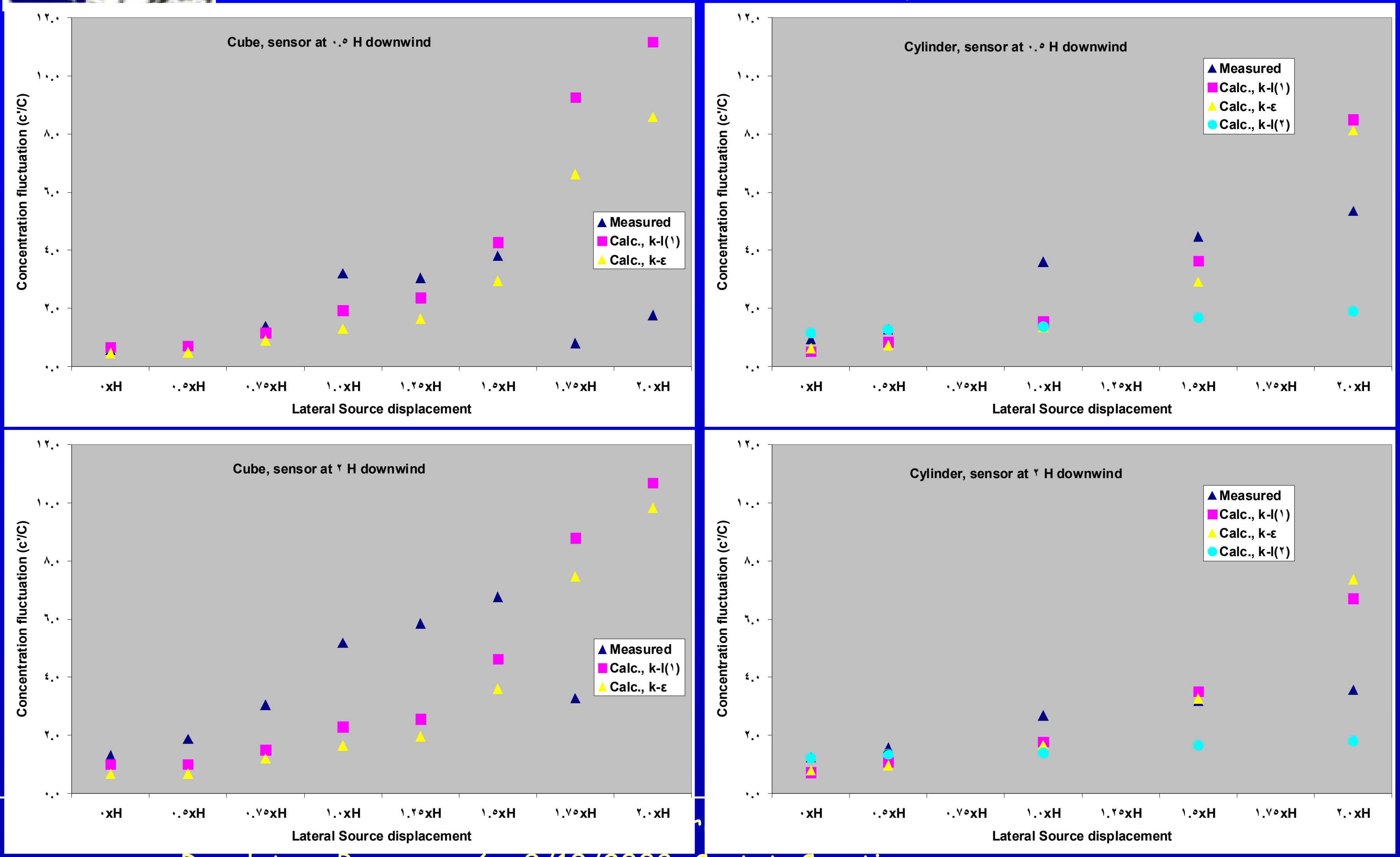

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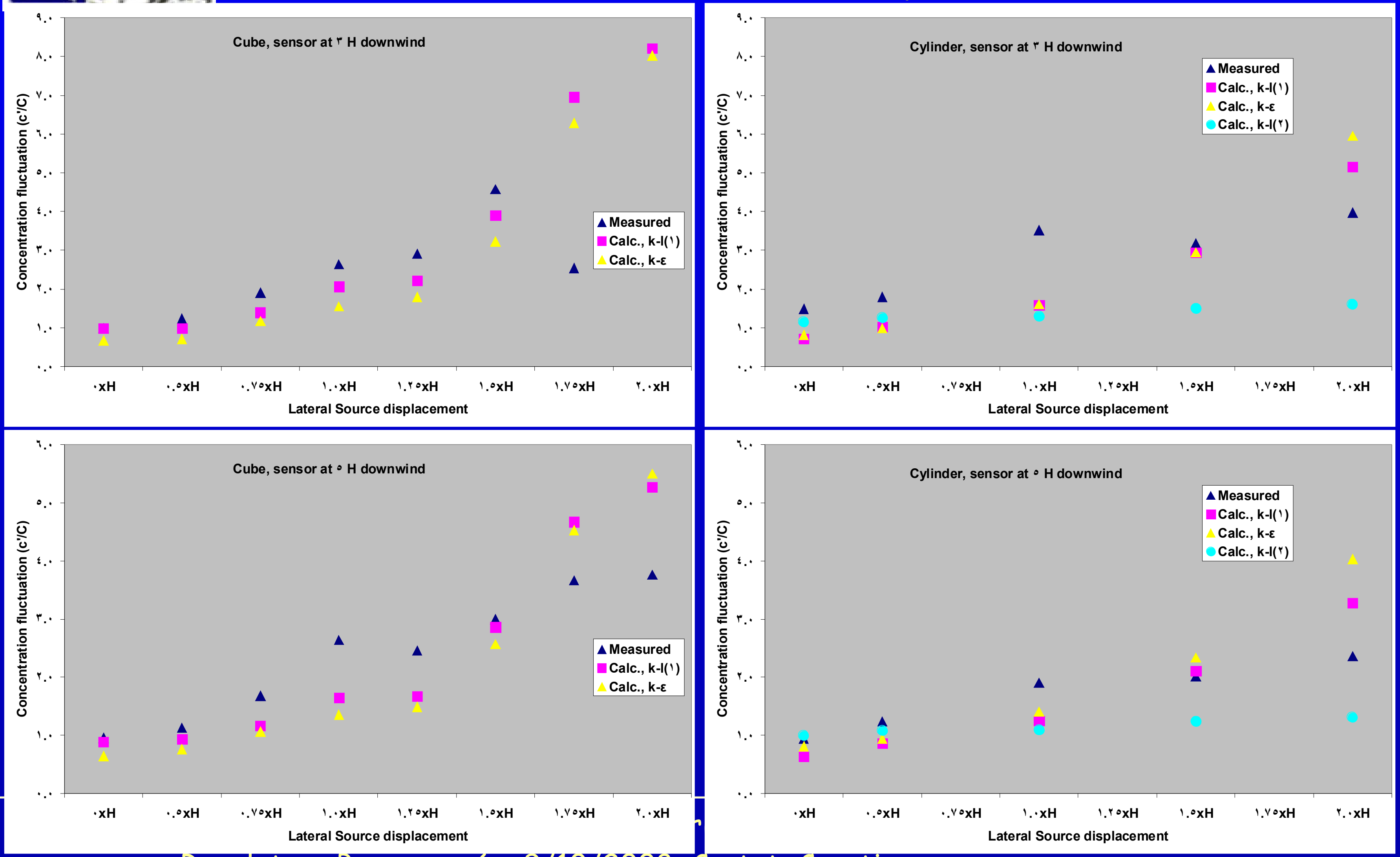

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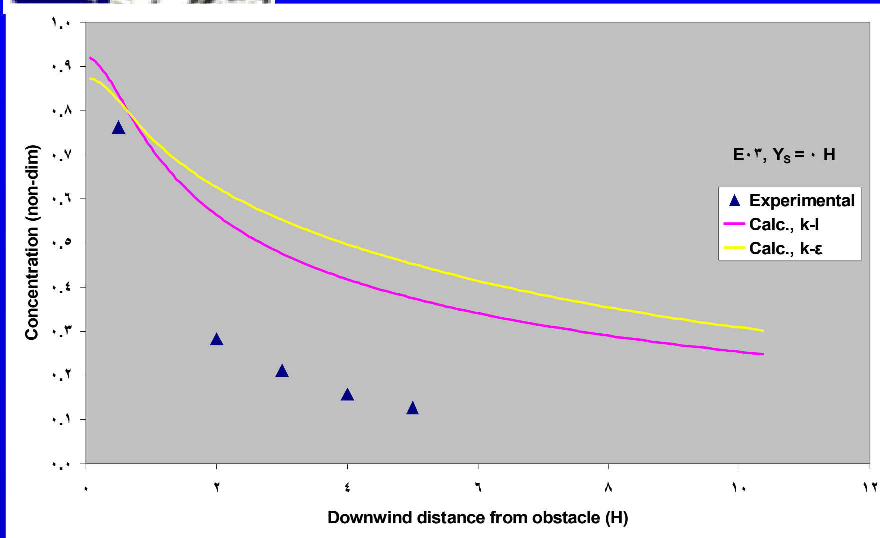

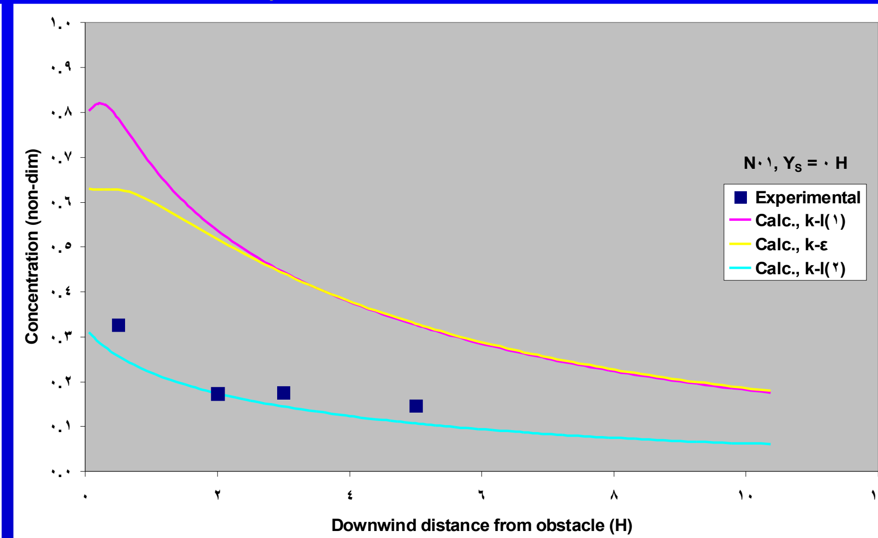

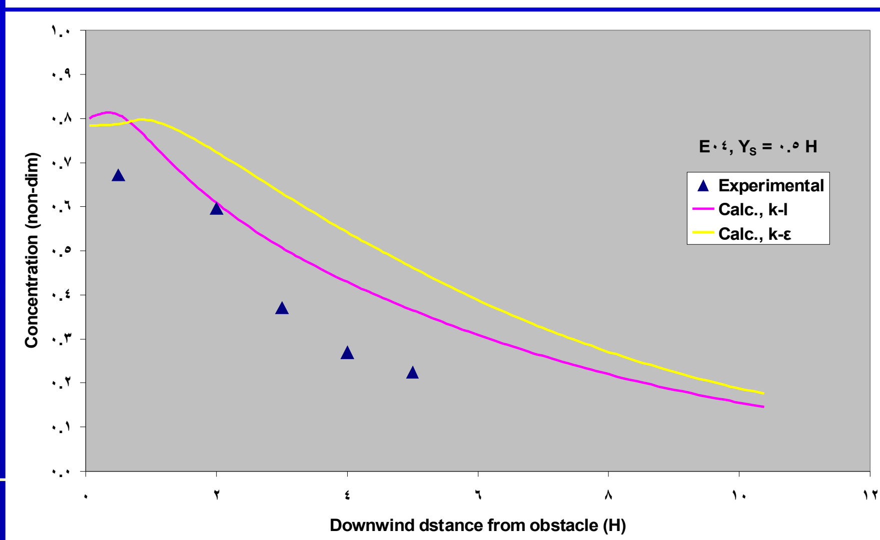

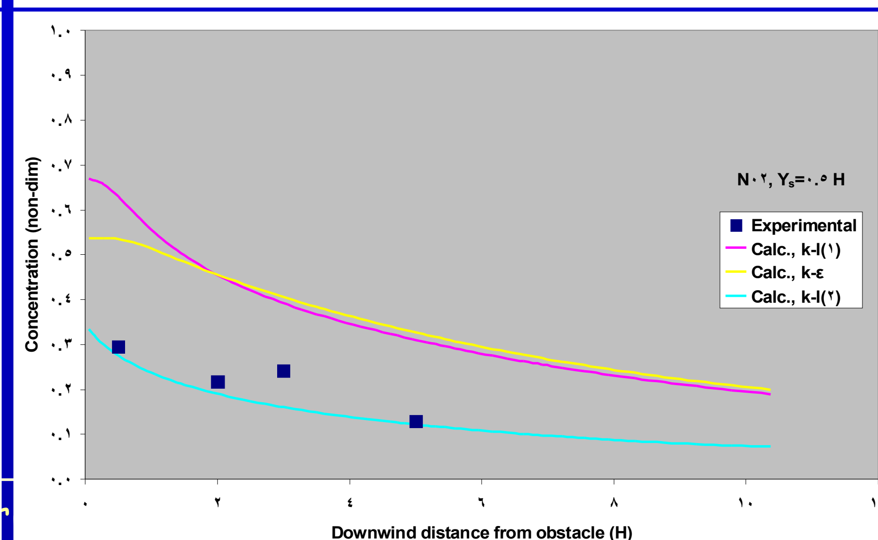

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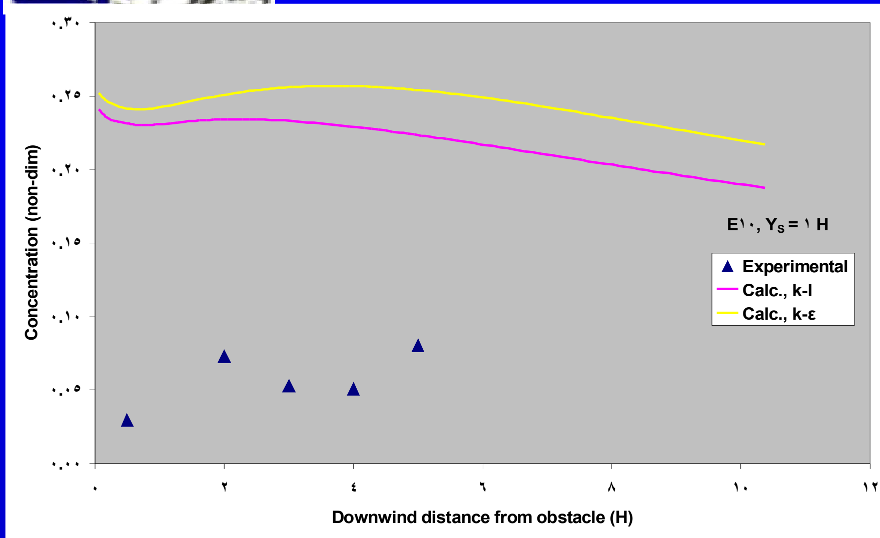

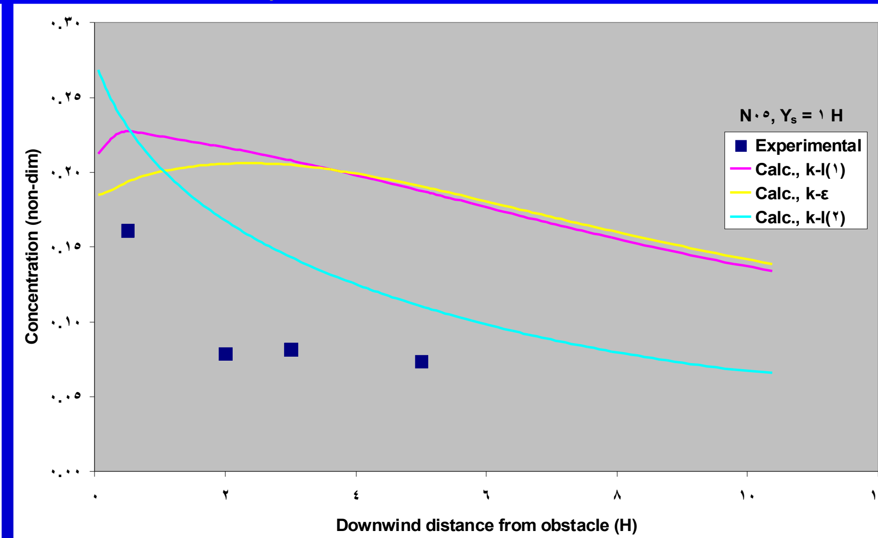

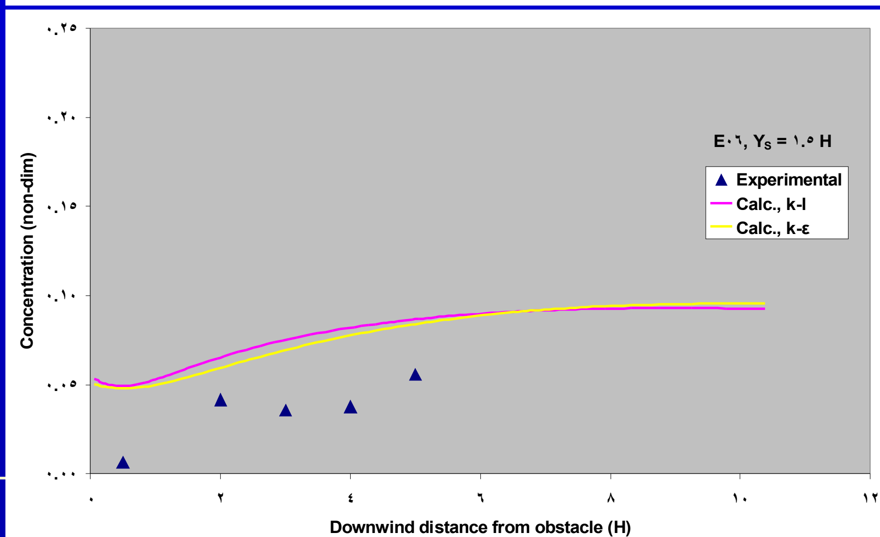

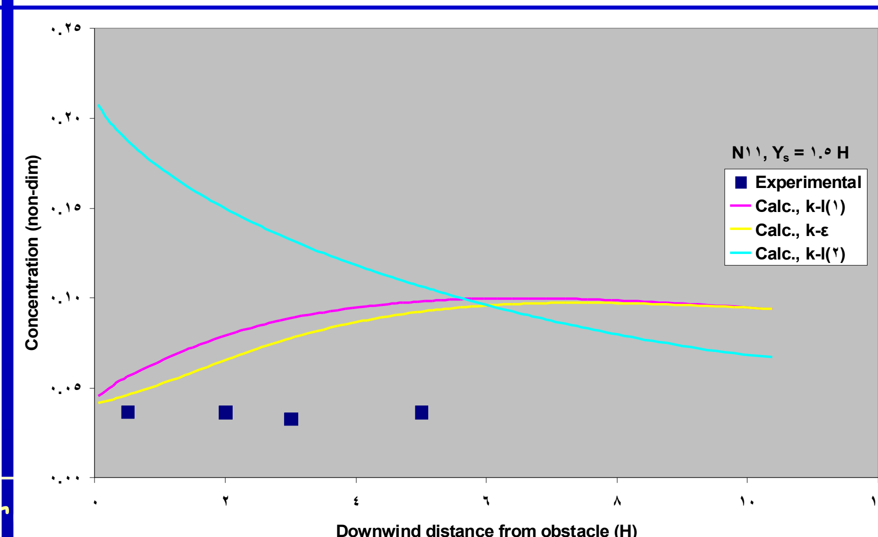

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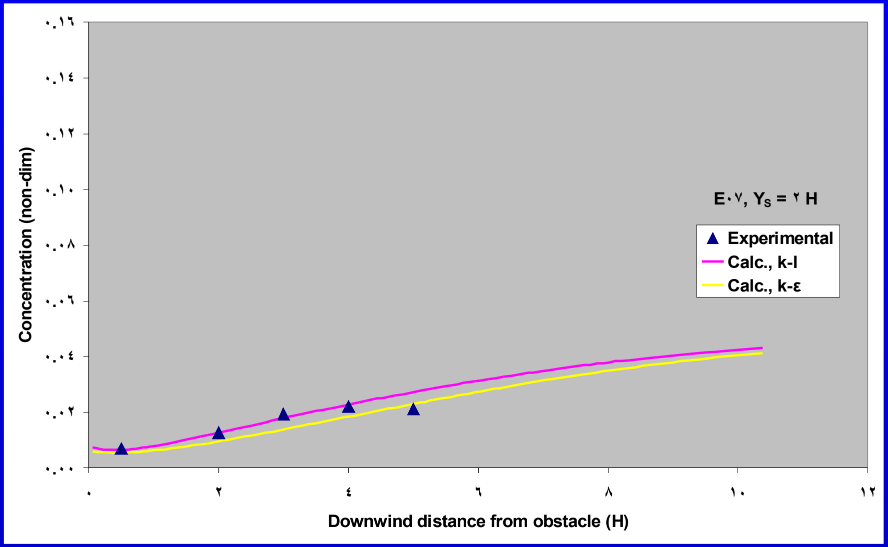

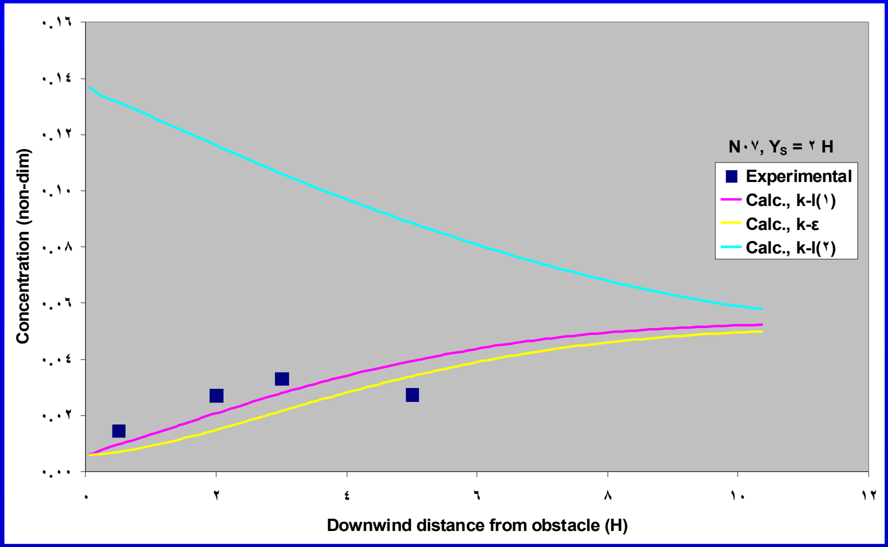

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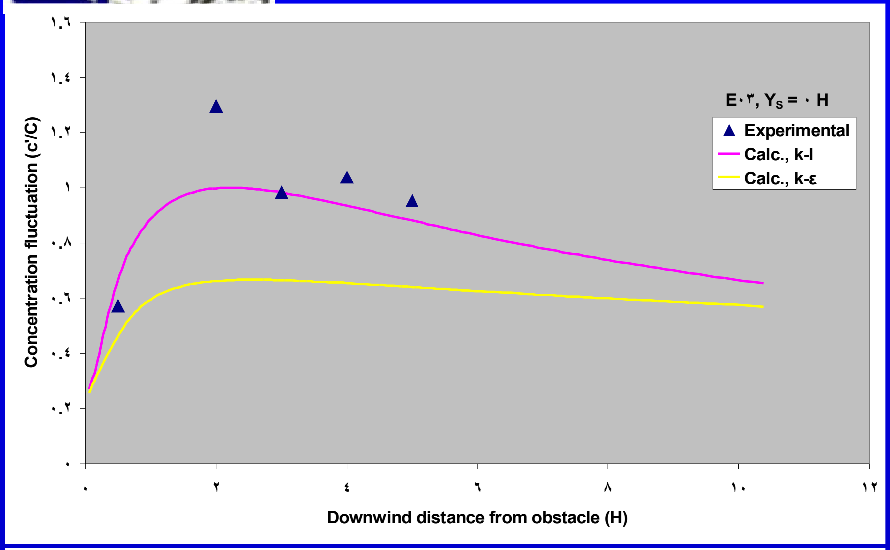
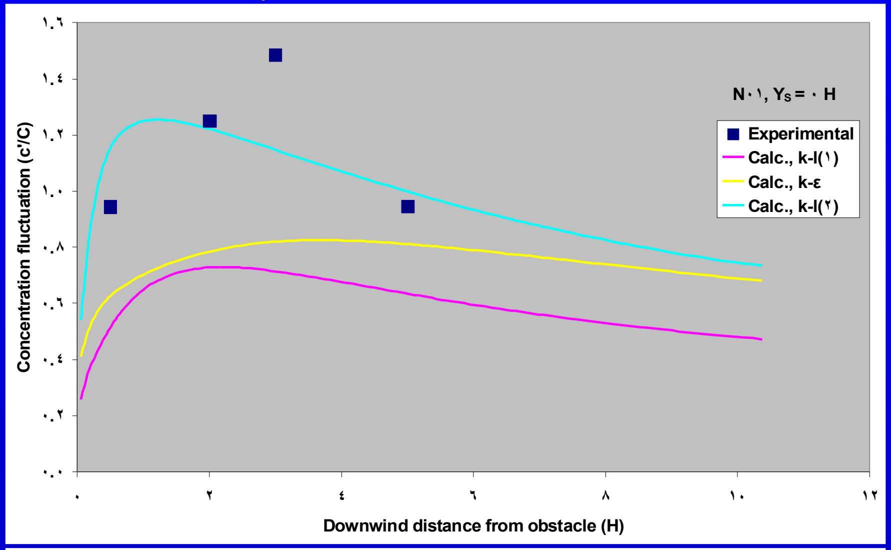
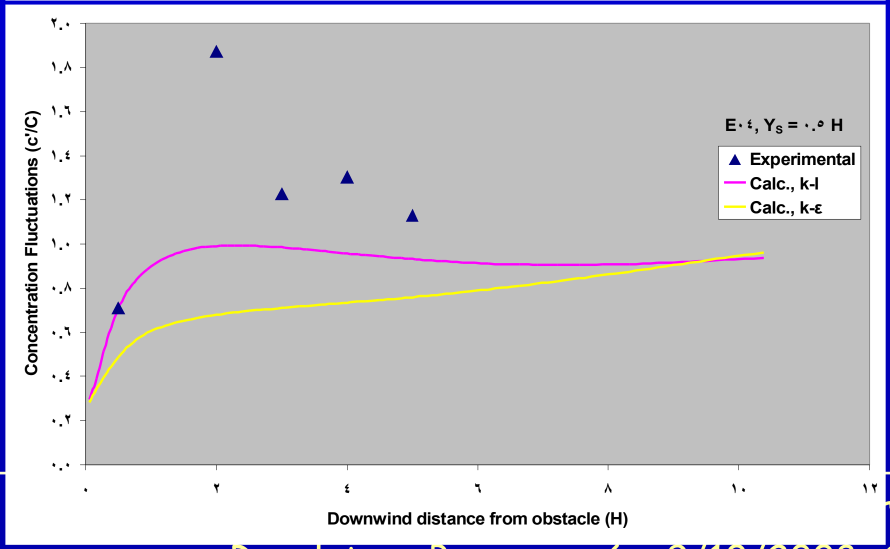
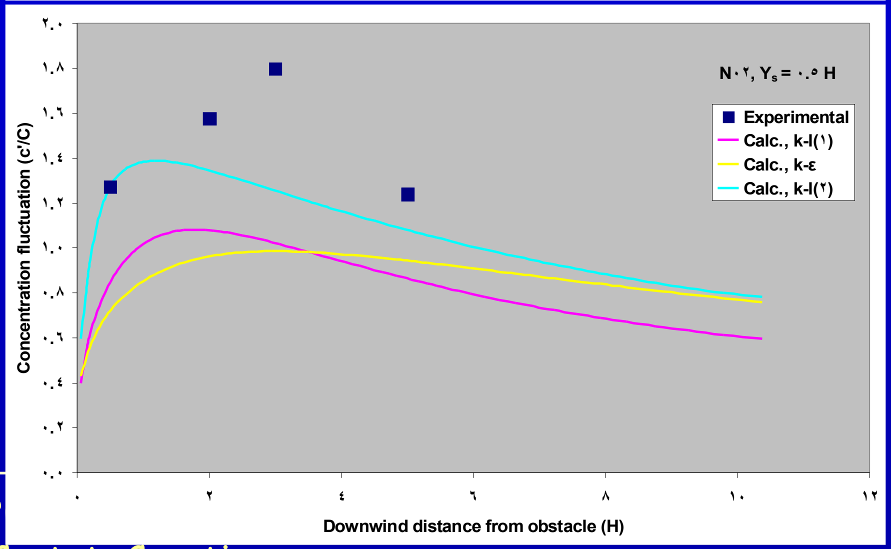
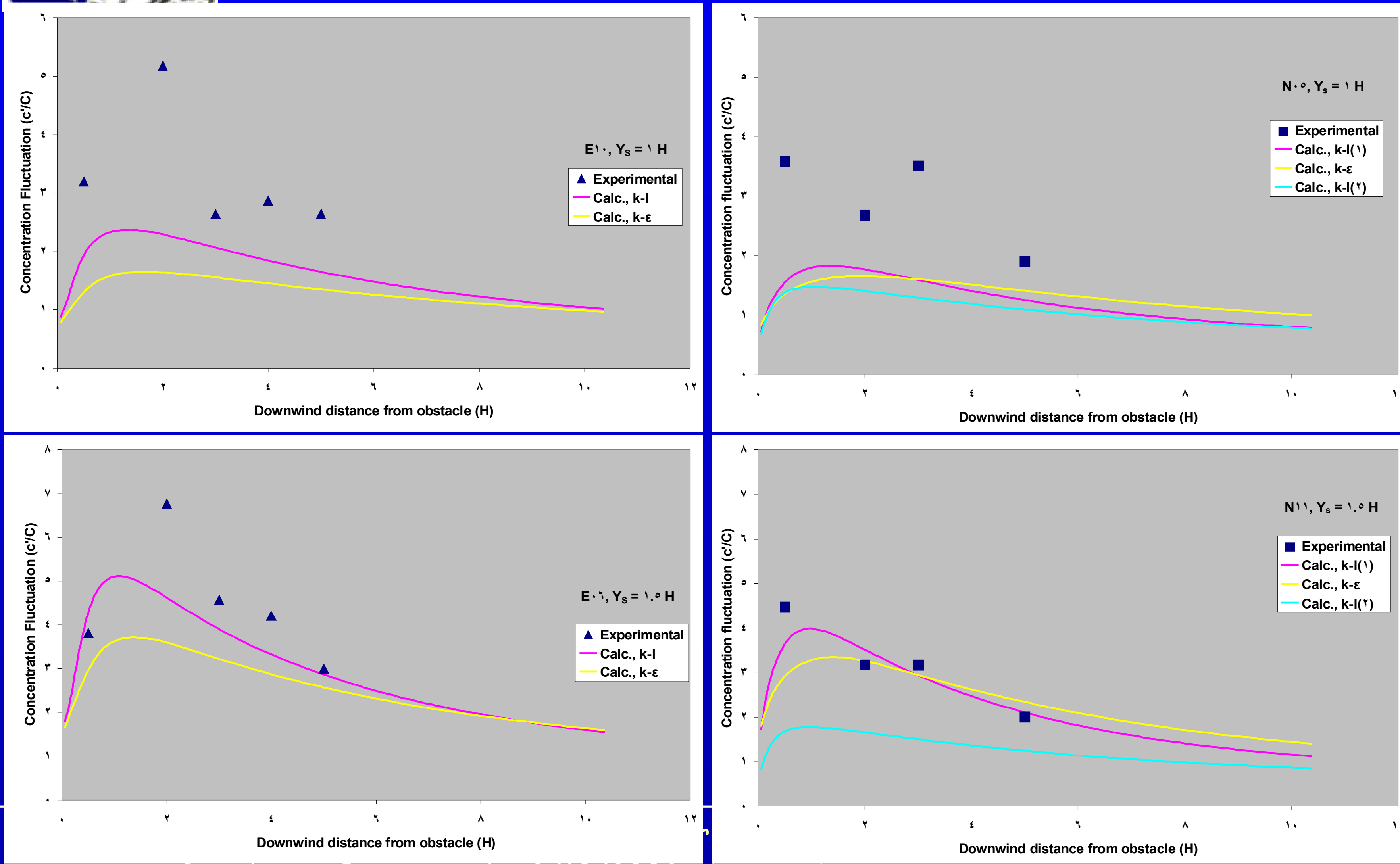








Model evaluation: comparison between cube and cylinder cases



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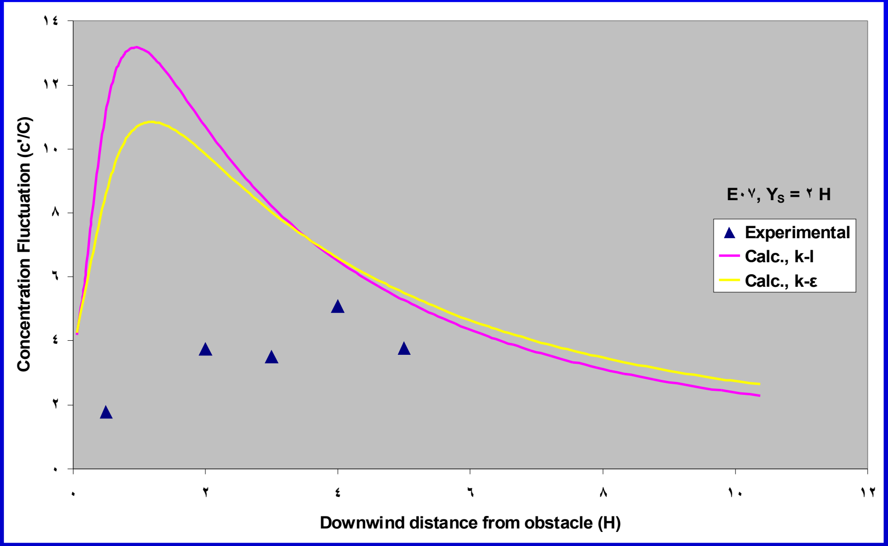

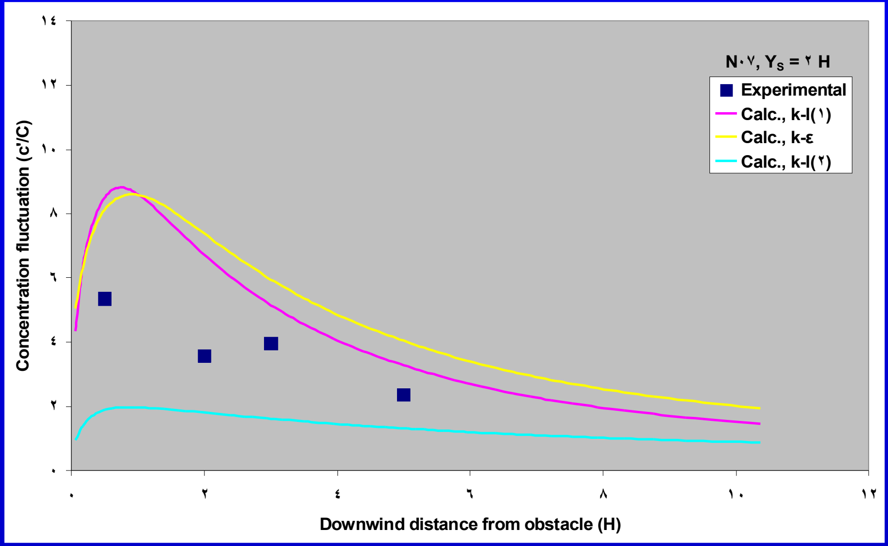

Summary and conclusions (1)

- Computational simulations of atmospheric dispersion experiments around isolated obstacles in the field
- CFD code ADREA-HF: dispersion of positively or negatively buoyant gases in complicated geometries
- Single cylindrical obstacle normal to the mean wind direction and two upwind sources of ammonia and propane, with the ammonia source located at different lateral positions
- Concentrations and concentration fluctuations for both gases were calculated by the model and compared with the experimental results
- Comparisons of experimental and model results with the case of dispersion around an isolated cubical obstacle are also presented and discussed

Summary and conclusions (2)

- Analysis of experimental results:
  - Variation of ammonia concentrations, concentration fluctuations and intermittency as the source is displaced laterally
    - Source at 0. H and 0.5 H: higher concentrations for cube
    - Sharper decrease of concentration with source displacement
    - Concentration peaks for source at 0.5 H (2, 3 and 5 H downwind)
    - Cylinder: fluctuations increase, cube: fluctuations peak for source at 1.5 H off
    - Intermittency increases with source displacement, more sharply for cube
- Computational results: k-l (2 versions for cylinder) and k-ε turbulence closure schemes tested

Summary and conclusions (3)

- Model performance evaluation:
  - "Scatter" plots for cylinder case
    - Ammonia concentrations
      - k-l(1) and k-ε similar performance, around factor-of-2
      - k-l(1) more points inside the factor-of-2 range, large overestimation for cases with large source displacement
    - Ammonia concentration StD
      - Most points inside the factor-of-2 range for all models
    - Ammonia concentration fluctuations
      - Most points inside the factor-of-2 range for all models
      - k-l(2) model results show little variation

Summary and conclusions (4)

- Model performance evaluation:
  - Propane results statistics:
    - "Ensemble" averages (same source position, stability conditions, similar wind)
    - The model performance for the cube case was better than for the cylinder case
    - The ratio Calc. / Exper. for concentrations is 2 times higher and for concentration StD is 3 times higher in the cylinder case
  - Ammonia concentration variation as the source is displaced laterally
    - k-l(1) and k-ε model results are similar and in general overestimate. Some peaks are predicted, only for the cube
    - k-l(2) model results are better for small source displacements but show little variation

Summary and conclusions (5)

- Model performance evaluation:
  - Ammonia concentration fluctuation variation as the source is displaced laterally
    - Models do not predict the experimental peak for the cube for source displaced 1.5 H off the centreline
    - k-l(2) model results show very little variation
  - Ammonia concentration profiles downwind
    - Experimental values are higher for the cube than for the cylinder close to the obstacle and decrease more sharply
    - k-l(1) and k-ε results are similar and overestimate the experimental values for source placed at 0, 0.5, 1 and 1.5 H off the centreline
    - k-l(2) agree better for source placed at 0, 0.5, 1 H but are worse for source placed at 1.5 and 2 H off the centreline

Summary and conclusions (6)

- Model performance evaluation:
  - Ammonia concentration fluctuations profiles downwind
    - Model results peaks are "weaker" than the experimental and occur closer to the obstacle
    - For the cylinder case no peak is observed in the experimental data for source displacement above 1 H off centreline
    - k-l(2) model results are better for smaller source displacements, k-l(1) and k-ε are better for larger source displacements.
- Future work:
  - More detailed analysis of the differences in results and model performance between cubical and cylindrical obstacle cases