Hydrol. Earth Syst. Sci. Discuss., 4, S2263–S2272, 2008
www.hydrol-earth-syst-sci-discuss.net/4/S2263/2008/

Hydrology and Earth System Sciences Discussions

Interactive comment on "On the measurement of solute concentrations in 2-D flow tank experiments" *by* M. Konz et al.

M. Konz et al.

Received and published: 11 March 2008

We are grateful for the constructive comments of the two reviewers. They helped us to significantly improve the quality of the paper, and we tried to modify our manuscript and reply in detail to every single comment when carrying out major revisions of the manuscript for submission to HESS. Referee #2

The referee raised in total 11 specific comments. In the following we will comment on each of the points. For convenience, we cite the referee comment first (italic).

1. Comment:

“The resistivity method is claimed to be "New". However, it is unclear exactly what is new in this well-established method. The authors claim that no one has provided a detailed presentation of resistively measurement system and compared this results against photometric method. Such a presentation is a worthy tutorial-type contribution but it should NOT be claimed as "New". The authors should state upfront that the goal is provide the practical details for implementing a commonly used resistivity method for porous media systems. In that case, perhaps they should expand the discussions on resistivity methods and provide a cook-book type step-by-step procedure to use the method.”

We agree with the referee that the terminology “newly developed method” is misleading and we changed this in the revised version of the manuscript. However, to the best of our knowledge no one has demonstrated so far a technology that enables the measurement of large concentration ranges from 0-300 g/l within the porous media using electrode arrays. Siliman and Simpson (1987) used electrode arrays in a narrow interval of low concentrations from 50 to 1000 mg/l. Hassanizadeh and Leijnse (1995) took platinum disc electrodes facing each other to measure salt concentrations in the range of 0.001 to 0.24 kg kg-1 (about 280 g/l). This technique is different to ours because they measure the resitivity between the plates, which are placed on both sides of the flow domain and not within the porous media. For 2D applications this is sufficient, however if one wants to measure concentrations in larger scale 3D tanks the plate methodology is not practicable. An example for such a 3D application is given in Danquigny et al. (2004). The electrode system developed in our study can be used for these kind of experiments. The goal of this study is to demonstrate technical details of the two independent measurement techniques and evaluate their applicability and reliability. From the referee’s comment we learn that this is not clear to the reader and we extended the discussion of advantages and disadvantages of the methods. To our understanding and especially from the experience gained during the development of the resistivity system not the usage of the RMC system is complicated but the technical details and the construction of the system. Thus, we aim to present the constructional and technical details of the system to share this knowledge with other scientist interested to work with such a technique.

The application of the system itself and the data processing does not significantly differ from standard techniques.

2. Comment:

“ The generic conclusion of this work is that it the image analysis is better than resistivity approach for variable-density problems involving salts. If that is the case, why should one learn about resisitivity methods? Image analysis is relatively easy and in-expensive, isn’t it??”

Image analysis is a useful tool in 2-D applications. It is a question of purpose which method should be used. If the measurement area is essential to know, the image analysis is the better choice. Thus, we conclude that the image analysis method is better for benchmark experiments. However, as discussed above the resistivity method is a valuable technology in 3D experiments. The method is very precise and perturbations such as flare effects are excluded. Therefore, we do not state that the image analysis method generally outperforms the resistivity method.

3. Comment:

“In the image analysis section, the key contribution appears to be the idea of relating measured intensities directly to concentration without standradization of optical densities. They identify this need based on Schincariol 1993 work. Interestingly, Schincarol and also the co-author Frank Schwartz have published multiple papers since then, including a recent 2007 paper in the journal of contaminant hydrology. The proposed "idea" should be evaluated in the context of all these recent work.”

Schincariol et al. (1993) and McNeil et al. (2006) among others convert the measured intensities to optical density in order to account for fluctuations in brightness from one image to the other. Optical density D is non-linearly related to intensity I by:

where a is simply a constant of proportionality. Schincariol et al. (1993) and McNeil et al. (2006) argued that the standardization of images to optical density is necessary

HESSD

4, S2263–S2272, 2008

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

because variations in lightning, exposure and film development result in non-uniform image intensity between successive images. However, modern digital cameras collect linear intensity values and store those measurements linearly on the chip. The Nikon D70, used in our experiments, provides two types of data of one image: 1. The linear raw data stored as .nef 2. Automatically, non-linearly adjusted images as .jpg RAW data (which Nikon call NEF data, an acronym for Nikon Electronic File) is the output from each of the original red, green and blue sensitive pixels of the image sensor, after being read out of the array by the array electronics and passing through an analogue to digital converter. Now one of two things can be done with the RAW data. It can be stored on the memory card, or it can be further processed to yield a JPEG image. If the data is stored as a JPEG file, it goes through the Bayer interpolation, is modified by in camera set parameters such as white balance, saturation, sharpness, contrast etc, is subject to JPEG compression and then stored. The advantage of saving JPEG data is that the file size is smaller and the file can be directly read by many programs or can be sent directly to a printer. The disadvantage is that there is a quality loss, the amount of loss depending on how much compression is used and that the data are not linear any more. Thus, the more complex correction method used in Rahman et al. (2005) or the standardization of images to optical density is only necessary if: 1. Analogue images are taken and the film has to be developed and scanned to convert the image to digital data 2. Non-linearly adjusted images (.jpg) are used In our case we used the linear raw data. The used converter, dcraw, generates linear 16-bit tiff images from the raw data. A linear development means that no gamma correction has been applied yet (typ. gamma=2.2), and thus levels are distributed along the histogram in a linear way being each of them proportional to the amount of light (number of photons) that the pixel was able to capture during the exposure (for details of dcraw please refer to e.g. http://www.guillermoluijk.com/tutorial/dcraw/index_en.htm). Therefore, the intensity correction based on reference white intensity (Iref) is sufficient:

Further, a more complex non-linear correction is contra productive, because it brings artificial non-linearity into the data. Nowadays, optical densities are only used for image processing in terms of visual improvement of colours or brightness (personal communication Dr. Rosenthaler, Visual Media Lab, Uni Basel). This discussion is added in the new version of the manuscript.

4. Comment:

“Page-7- How can you relate intensity of dye to salt concentration? What is the salt and the dye move at different rate due to differences in the diffusivity values? Have you checked this?”

In order to relate a given value of intensity to a concentration of salt or dye, calibration runs were made with predetermined dye-salt concentrations. In the calibration experiment, solutions of predetermined salt water-dye concentrations (0.5, 3, 5, 8, 10, 15, 20, 40, 70, 100 g/l of salt water, the dye concentration is always 1/100 of the salt concentration) were pumped in the tank and images were taken. Due to the higher ion activity of the saltwater we used salt-dye solutions for calibration. This accounts for possible intensity differences between equal concentrated solutions of dye-saltwater and dye-freshwater. Different diffusivity could cause separation of dye and saltwater leading to erroneous concentration determinations. In the literature other authors have used various dyes including food color to track the movement of dense saltwater in laboratory-scale aquifer models. Neither Schincariol et al. (1993), Swartz and Schwartz (1998) nor Goswami and Clement (2007) reported difficulties due to dye-salt separation. The later used a red food color comparable to ours. In order to evaluate the applicability of E124 we performed batch experiments using the same porous media as for the experiments. Neither sorption nor degradation over experimental time scales could be observed using a spectrometer (Shimadzu UV-1700 Pharma Spec) to analyze dye concentration. This agrees well with Rahman et al. (2005) who used the same color in their experiments. Additional column experiments (1m length) were conducted with different salt-dye solutions and compared breakthrough curves of salt and colour. The salt concentrations were measured using standard resistivity cells (WTW) and the color concentrations were determined using the spectrometer (Shimadzu UV-

HESSD

4, S2263–S2272, 2008

Interactive Comment

1700 Pharma Spec). No separation could be observed. Further, differences in the diffusivity are of minor importance in experiments dominated by advection as it is the case in our experiments. We present this discussion in the new manuscript.

5. Comment:

“ The intensity figures (e.g, fig 3) has several spikes, what are causes of these spikes? Did they affect your overall data quality?”

The spikes in the raw data (first four graphs) in Figure 3 could be caused by fluctuations in electricity supply. Actually, the intensities shown in the figure were recorded over two days including the night. 0-600 was taken in the evening and over night, whereas 600 onwards are images taken in the morning and over the day. This could explain the increased fluctuations in energy supply during the day. However as demonstrated in 3.2 these fluctuations can be corrected applying the correction method based on the reference white. Thus, the spikes do not influence the data quality. However, for future experiments we recommend illumination systems with a constant energy level to completely avoid those fluctuations.

6. Comment:

“The authors state that they get 16 bit tiff images (after conversion) giving them 65536 intensity values. However, their camera Nikon D 70 acquires only 12 bit images which provide 4096 intensity values. Which means rest of the intensity values are numerically generated (from a proprietary algorithm-dcraw) and cannot be used as true pepresentation of intensity values from the experiment. It is unclear what is really gained by artificially generating 16 bit information from a 12 bit native image?”

PC systems work in either 8 bit or 16 bit but not in 12 bit. Thus, one has the choice either to reduce the 12 bit data to 8 bit, accompanied by data loss or to blow it up to 16 bit. The conversion to .tiff images is a necessary step because the data need to be visualized on the screen in order to determine the correct position of the observation

HESSD

4, S2263–S2272, 2008

points. We used the converter dcraw which enables linear 16-bit transformation. Linear transformation means spreading the 4096 shades of the 12 bit raw image over 65536 shades in a linear fashion (0 remains 0, 4096 becomes 65536 and 2048 becomes 32768).

7. Comment:

“ It is unclear how dye concentration was decided (100 g/l of salt was marked with 1 g/l of dye). How much dye should be used? Is dye concentration a function of salt concentration? Need some discussions that address the relative advantages and disadvantages of using very-high or very-low dye concentration levels?”

This is an interesting question! The intensity-concentration relation is non-linear, it means that with higher dye-salt concentrations intensities do not change the same way as for lower concentrations. Since we need to resolve concentration ranges from 0 to 100 g/l salt, 1 g/l dye concentration appears to be adequate to mark the maximum salt concentration of 100 g/l. The initial concentration (max concentration) of dye must be high enough that even with a large dilution, e.g. 0.5 g/l salt (corresponding to 0.005 g/l color) the plume can be optically differentiated from the ambient pore water. However, the maximum concentration needs to be below intensity saturation to enable the correct resolution of the high concentrations. This discussion is part of the revised manuscript.

8. Comment:

“ Abstract does not read well, need to clearly emphasize your contribution in both abstract and conclusion sections”

We improved this in the revised version of the manuscript.

9. Comment:

“I remember reading some papers on image analysis using other technique (e.g., gamma ray by Oostrom et al. in vadoze zone journal 2007, I think?). These analysts have done extensive review of error analysis. The analysis in this paper appears

HESSD

4, S2263–S2272, 2008

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

to be too simple, please review these studies and develop your error analysis based on literature information.”

We introduce a new section, 3.6, in the new manuscript discussing the error assessment. The error of intensity determination of the calibration concentrations is taken into account by standard deviations of the respective calibration step. To be conservative, we took the largest error, which can be observed for 100 g/l in our calibration experiments for the error assessment. This is applied on the intensities measured during the experiment (+/- standard deviation). We know that there is an additional error of +3% in the measured intensities due to the lens flare effect. Therefore, the concentrations are given with confidential limits (see Figure 15 of the revised manuscript). The lower boundary is calculated from the processed intensity Icorr + 1.5 % of error, whereas for the upper boundary Icorr - 4.5% is used to derive concentrations than the intensities are converted to concentrations using the second order exponential equation. The mass balance can be calculated based on the given mass of salt entering the domain and the mass determined by image analysis at different time steps. The image analysis takes into account the porosity and the depth of the tank. The impact of lens flare should be more pronounced if only a small portion of the domain is filled with the dark solution. Whereas, the effect should be reduced if the tank is filled by the dark solution. In order to analyses this we conducted a fifth experiment, E5. The dye-salt solution enters the domain over one inlet at the margin of the tank with a constant well-known flow rate. The concentration is 100 g/l of NaCl. Each 30 sec an image is taken and we analyzed the images after 10 and 45 minutes. Figure 10 of the revised manuscript shows the spatial distribution of the saltwater (red). The 10 min image delivers an underestimation of the total mass of -4.2 % compared to the mass entering the domain. This is within the range of expected lens flare errors. After 45 min the bright region of the tank is significantly reduced and the mass error accounts for 1.6 %. The method overestimates the total mass. Since the porosity is used to calculate the mass possible small errors in this parameter could cause the overestimation. However, this would affect the mass after 10 min in the same way. Due to this analysis the parameters determined for each pixel are reliable and possible errors can be explained with the impact of lens flare. We consider this error assessment approach as reliable, because no non-linearity in raw data needs to be considered (see comment 3).

10. Comment:

“ The authors explore the impact of image resolution and lens flare. However, there does not seem to be any generality in their approach/analysis that will be of use to readers. Try to establish some guidelines on what to do and what not to do. Also, the entire problem of lens flare will become minimum if one does transmissive experiments, which the authors acknowledge is a better approach. Hence is the real use is unclear.”

Referee #1 states: “The paper is a an interesting contribution to this field and offers new insights in terms of the discussion of the errors. The most interesting conclusion is to my point of view the source of error due to the lens flare effects. One of the advantages of optical methods is that they allow for a concentration measurement over the whole medium at one time. The errors discussed here show the limitations of this capability.” We fully agree with this statement because most of the intermediate scale flow tank experiments use reflection method with potential exposure to lens flare effects. To the best of our knowledge we firstly show the impact of this effect on concentration measurement. This helps researchers i.) to assess the experimental results already published in the peer literature, and ii.) to consider this source of errors in their experiments. Since this effect strongly depends on the specific experimental conditions general guidelines as asked by the referee #2 are hard to define, however in section 3.5 we present and discuss an experiment with an attached mask that significantly reduces the impact of flare effects (Figure 9 of the revised manuscript). Further, we demonstrate an approach to systematically estimate the error caused by the effect (section 3.5, comment 9). These two analyses are generally applicable and can be used by other researchers. The necessity of light reflection techniques is discussed for Comment 2 of referee #1. However, we acknowledge all discussion and contribution to

HESSD

4, S2263–S2272, 2008

Interactive Comment

this topic! There is a clear need for further research in error estimation and reliability of the methodology. Our paper is a contribution to raise the awareness of potential errors.

11. Comment:

“Only temporal variations in concentrations are provided. Can you use the method to map plume contours? This is important since most analysts use image analysis to study spatial variations.”

If one has images without the mask contour lines can be computed for any concentration levels. However, because this is shown in many studies (e.g. Schincariol et al., 1990, McNeil et al., 2006, Goswami and Clement, 2007) in our study we focus on breakthrough curves (BCs). In addition, BCs at distinct points with high temporal resolution are necessary for benchmarking numerical codes.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 4, 4175, 2007.

HESSD

4, S2263–S2272, 2008

Interactive Comment