Flow fields and sedimentation patterns in rectangular shallow reservoirs

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Summary

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- Experimental set-up
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- Velocity measurement techniques (LSPIV-UVP)
- Experimental results about flow fields
- Comparison with results of other similar studies
- Tests with sediments supplying
- Conclusions
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Research context

Engineering problem: dealing with reservoir sedimentation (need to know the trap efficiency of the reservoir, in order to plan effective sediments management operations)

Sediments deposits are strongly influenced by the velocity flow field (main jet direction, vortex structures, recirculation zones,…) developing in the reservoir

Reservoir geometry strongly influences the kind of velocity flow field

Need to understand the influence of reservoir geometry (L/B ratio, inlet and outlet location,…) on the flow field
The experimental set-up

Hydraulic conditions:
- \( Q = 7 \text{ l/s} \)
- \( h = 0.2 \text{ m} \)
- \( Fr_{in} = 0.1 \)
- \( Re_{in} = 4V_{in} h/\nu = 112'000 \)

Geometric characteristics:
- \( L_{max} = 6 \text{ m} \)
- \( B_{max} = 4 \text{ m} \)
- \( h_{max} = 0.3 \text{ m} \)
- \( b = 0.25 \text{ m} \)
Previous studies

S. Kantoush (2008) started to carry out flow fields investigations in the experimental facility at LCH, analyzing flow fields and sedimentation for some different reservoir geometries:

A non-symmetric flow field can develop for some reservoir configurations, despite the symmetry of the geometry!
Aim of the actual research

- Investigate the role of two non dimensional parameters, ER and AR, on the typology of flow field developing in the reservoir.

- Analyze the influence of an asymmetric location of the inlet and outlet channel on flow patterns and sediments deposits (location of deposits and volume of sediments trapped in the reservoir).
LSPIV technique

Cross – correlation algorithm between hundreds of couples of successive images

Average 2D surface velocity flow field

Acquisition parameters:
- Frequency = 12 MHz
- Frames per seconds = 8.22 FPS
- Total number of acquired images = 1500
- Duration of each acquisition = 3’
UVP measurements

The 2 horizontal components of velocity were measured by 8 UVP transducers forming a movable square grid.

20 maps were produced for every grid position and then averaged.
Experimental results

$\text{Re}_{in} = 112'000; \text{Fr}_{in} = 0.1; h/b = 0.8$
Flow fields typologies

a) Asymmetric flow field A1
Experimental results

\[ \text{Re}_{\text{in}} = 112'000; \quad \text{Fr}_{\text{in}} = 0.1; \quad h/b = 0.8 \]
Flow fields typologies

d) Asymmetric flow field A2
(asymmetric A1 + channel-like flow CH-L)

e) Channel-like flow CH-L
$(B/b)_{\text{max}} = 2$
Experimental results

Re_{in} = 112'000; Fr_{in} = 0.1; h/b = 0.8

(B/b)_{max} = 2
Flow fields typologies

b) Symmetric flow field S1 (4 main eddies)
Re_{in} = 112'000; \text{Fr}_{in} = 0.1; \ h/b = 0.8
Flow fields typologies

c) Symmetric flow field S0 (2 main eddies) L/B ≤ 1
Experimental results

Transition between symmetric and asymmetric flow field:
L = 5.3 – 5.8 m (at fixed width B = 4 m)

Re_{in} = 112'000; Fr_{in} = 0.1; h/b = 0.8

Unstable flow field:
Bifurcation zone

(B/b)_{max} = 2

Unstable flow field:
Bifurcation zone
Comparison with similar Research

Tests carried out at Liège University in a similar experimental facility

Tests carried out in different hydraulic conditions ($Fr_{in} = 0.2$): different flow fields can develop for a same geometry depending on Fr and h/B!
Tests with suspended sediments: different inlet and outlet locations

Suspended load can represent a big amount of reservoir volume loss (peak values of 4 g/l during floods in Rhône River)

Main parameters for tests with suspended sediments:

- $\rho_s = 1460 \text{ kg/m}^3$
- $d_{50} = 89 \mu\text{m}$ (crushed walnuts shells)
- $v_s = 2 \text{ mm/s}$ (Stokes’ law on $d_{50}$)
- 4 hours of sediment supplying (total amount of sediments: 200 kg)
- $C_{in} = 2 \text{ g/l}$ (average) real time monitoring by turbidimeter
- $Q_s = 0.027 \text{ kg/s}$

\[ C = 0.0037 \cdot NTU + 0.0557 \]

$C =$ solid concentration [g/l];

$NTU =$ number of turbidity units

Similarity at field scale (geometric scale 1:50):

- $C_{in} = 3.6 \text{ g/l}$
- $\rho_s = 2650 \text{ kg/m}^3$
- $d_{50} = 0.13 \text{ mm}$
- $v_s = 14 \text{ mm/s}$
Laser measurements

The thickness of sediments deposits was measured after 2 hours of test and at the end of the experiment (4 hours), by a laser placed in a known reference system of coordinates.

\[
d = 0.05 \cdot V - 0.0301
\]

- \( d \) = distance between the laser light source and the top of the deposits;
- \( V \) = voltage in output from the laser and recorded by Labview software.

\[\rho_{\text{dep}} = 250 \text{ kg/mc} \] (high water content)

Volume [mc] of sediments deposits

Density of sediments deposits

Weight [kg] of trapped sediments
Results of tests with sediments

The outlet sediments concentration is about ½ of the inlet concentration. Small differences can be found in the trapping efficiency (TE), depending on inlet/outlet location.

\[ \frac{C_{in} - C_{out}}{C_{in}} = \frac{W_{dep}}{W_{in}} = TE = 0.6 \]

Symmetric configuration

TE was found to be constant for the whole test duration
Results of tests with sediments

The outlet sediments concentration is about $\frac{1}{2}$ of the inlet concentration. Small differences can be found in the trapping efficiency (TE), depending on inlet/outlet location.

Inlet on the right – Outlet on the right

\[
\frac{C_{in} - C_{out}}{C_{in}} = \frac{W_{dep}}{W_{in}} = TE = 0.54
\]

Velocity vectors

Velocity values [mm/s]

Sediments deposits thickness after 4 hours [mm]
Results of tests with sediments

Inlet on the right – Outlet on the left

\[ \frac{C_{in} - C_{out}}{C_{in}} = \frac{W_{dep}}{W_{in}} = TE = 0.56 \]
Results of tests with sediments

Inlet on the right – Outlet on the left

\[
\frac{C_{in} - C_{out}}{C_{in}} = \frac{W_{dep}}{W_{in}} = TE = 0.56
\]

Flow pattern with sediments supplying (after only 30’ of sediment inflow)

Flow pattern without sediments supplying
Results of tests with sediments

Inlet in the centre – Outlet on the left

\[
\frac{C_{\text{in}} - C_{\text{out}}}{C_{\text{in}}} = \frac{W_{\text{dep}}}{W_{\text{in}}} = TE = 0.58
\]

Velocity vectors

Velocity values [mm/s]

Sediments deposits thickness after 4 hours [mm]
Conclusions (1)

• The influence of geometric non-dimensional parameters L/B and B/b on flow field typology (symmetric S1 or S0, asymmetric A1 or A2, and channel-like flow CH-L) in rectangular shallow reservoirs at fixed hydraulic conditions (Fr_{in} = 0.1 \text{ Re}_{in} = 112'000) was investigated;

• A critical zone of transition between the symmetric S1 flow field and the asymmetric A1 one, characterized by an unstable flow field was found (bifurcation of the Navier-Stokes equations’ solution);

• A comparison with similar tests carried out by other researchers strengthened the results of the actual study and leads to further investigations.
Conclusions (2)

• Velocity flow fields and sediments deposits in reservoir configurations characterized by asymmetric locations of the inlet and outlet channel were investigated;

• Experiments showed that an asymmetric locations of the inlet and outlet channels don’t affect significantly trapping efficiency, that was constant during the whole duration of the tests (TE≈0.55-0.6);

• The main part of suspended solids in the performed experiments sediment along the main jet, with a maximum thickness of 15-20%h at the end of 4 hours of test;

• The influence of the hydraulic flow field on sediments deposits was confirmed and also a feedback of sediments deposits on the hydraulic flow field was demonstrated.
Outlook for further research

Evaluate the influence on the developing flow field of:

• Different bottom roughness;
• Water depth \( h \) and discharge \( Q \) (in terms of non-dimensional parameters \( Fr_{in}, Re_{in}, h/B \));
• Calibration and validations of numerical models;
• Comparison with real situations (sedimentation tanks, shallow ponds,…) at field scale.
Thanks for your attention

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