Journal of Engineering and Applied Sciences 2 (12): 1716-1723, 2007
ISSN: 1816-949X

Methodological and Experimental Approach of the Desilting by Injection

[1]L. Ouerdachi, [2]M.F. Habita and [1]H. Boutaghane
[1]Department of Hydraulics, [2]Department of Civil Engineering,
University of Badji Mokhtar, BP12 Annaba, 23000, Algeria

Abstract: Algeria is located in the category of countries poor in water resources, fast silting up passing the 65 millions of m3 year^{-1}. It reduced considerably storage capacity of many reservoirs. In order to remedy several inconveniences of dredging used mainly in Algeria, we propose a method that is like the Water Injection Dredging (WID). It consists in injecting water resulting in an overtaking of material resistance, from where it appears a failure area. Underflow provoked by opening of outlet gate acts like a flushing. It was possible to us to value volume recovered of restraint with a simplified theoretical formulation of injection and modelling of behaviour hydromechanics of injected soil massifs and resolution equations gotten by finite element. Survey is completed by a scale model study. One could provide interesting indications on efficiency of method proposed while showing existence of critical values for pressure and speed of injection; values open to several technological interpretations.

Key words: WID, porous media, desilting, dredging, injection, underflow

INTRODUCTION

UN classifies Algeria among 10 African countries that will know serious problems by 2025. It is located in category of the countries poor in water resources to the look of shortage doorstep fixed by UNDP or the one of rarity by World Bank. Specific erosion rate reaches most elevated values of North Africa 20 to 500 tons/km²/year (Kassoul *et al*., 1997; UNPD, 2005). This phenomenon entails fast silting up of numerous restraints of water that represents 0.86 Mm3s is 13.15% of total capacity of dams in exploitation in 2004 (6.54 Mm3). On basis of silting up rates ensuing of surveys bathymetric done by National agency of Dams, 17 dams will have lost 50% of their capacity from 2050 (Kassoul *et al*., 1997; UNPD, 2005). Preventive methods remain difficult to see impossible to mastering (Cravero and Guichon, 1989). Curative means dredging, flushing and racking are most advisable. In order to remedy several inconveniences for dredging, we propose a method whose philosophy ensues of combination of 2 approaches one curative and other preventive: Flushing and racking. Advantages that we hoped with this method are:

- Reduction of frequency intervention.
- Operate in the secondary settlement phase therefore, one allows sediment to have a time of stay more that the one that is permitted for the case of flushing.
- Reduction of the water consumption.
- Shorter action time than in the other methods.

SYNTHESIS AND METHODOLOGICAL ANALYSIS

Of the phenomena survey and the bibliographic knowledge state we keep the phenomenon complexity of the silting up and thin sediments behaviour in the different mechanisms in presence. Silting up process is influenced by macroscopic parameters, relative to the restraint and its environment that is:

- Reservoir topology.
- Protective degree of direct supply catchments.
- Tributary configuration and their of transport capacity.
- Geomorphology of the reservoir stratum.
- Operating mode.

Deposed material is composed substantially of three types of soil (clayey minerals, sand and silts; having a different mechanical behaviour and not reacting in an identical way to the actions of the environment in which they are.

So the big particles, sand, don't possess plasticity and cohesion whatever is their mineralogical nature, while the fine particles possess these properties to various degrees that depend on their mineralogical character and the nature of their environment and of their consolidation state.

Corresponding Author: L. Ouerdachi, Department of Hydraulics, University of Badji Mokhtar, BP12 Annaba, 23000, Algeria

Non clayey thin minerals that are the main components of the inorganic silts, in spite of their smallness don't possess any. At solid state; mud presents a critical threshold over which it can be eroded. Actually, brewing of silt by an out-flow creates shear stress that, if it passes this threshold called critical stress provokes a digging out of particles of the deposit surface. Authors link this stress to the limits of atterberg, what appear non meaningful because these limits are not intrinsic mechanical features of the materials, but only of the parameters relating to limit of materials state.
Partheniade law,

$$E = M[\frac{\tau_0}{\tau_c} - 1]$$

(Partheniades, 1965), the more used, concerns superficial erosion. It presents two major limitations; choice of erosion coefficient M that is described soon as constant, soon as dependent of concentration and determination of critical stress.

Mud properties are conditioned by several factors. Whereas for the sediments without only cohesion one is sufficient, diameter of the grains, determine erosion laws; for silt they depend of:

- Concentration.
- Grading.
- Mineralogical composition.
- Percentage of sand in presence.
- Consolidation state.
- Interstitial water saltiness.
- pH of waters.
- Middle ionic composition.

Rheological behaviour depends on the concentration and consolidation state of the silt that is very sensitive to the phenomena coagulation-flocculation and to settlement. Relations between the various cited parameters remained very uncertain and are often established only for some types of vases and some parameters, what is insufficient to model this material. Exam of various concrete case of silting up of reservoir highlighted the much diversity of the situations holding to the types of restraints and the nature of the settlement. It would be an illusion to research of global solution. Otherwise, facing silting up problems of the dams, the most ambitious objectives than one can fix could express:

- To limit sediment inflow.
- To predict mode of solid transport and sedimentation in dam in order to define a management limiting the silting up.
- To predict erosion mode and the speeds to put sediment suspension on again, it would permit to consider a piloting of the emptying.
- To improve existing systems.
- To finalize of new processes of desilting.

Neither preventive, nor curative means employees permitted to solve thorny problem of silting up until now. Preventive methods remain difficult to see impossible to mastering. Curative means dredging, flushing and racking are most advisable.

Dredging:

- Cost
- Implementation

Flushing:

- Impose one operating mode more or less rigorous.
- Consumption remains relatively elevated.
- Its superficial action.
- Erosion process start more or less after a length long (8-10 h).
- It only acts when silt is in primary consolidation phase, what imposes frequent operations.
- Its efficiency depends on the existence of an optimal flow that is not determined a priori.

Racking: Require special organs of discharge. Existence of density currents is necessary to be able to practice it. However, their springing and stability depend on a lot of factors.

In order to remedy several of the above inconveniences, we propose method whose conceptualization ensues of combination of two approaches one curative and other preventive: flushing and racking.

PHENOMENOLOGICAL APPROACH

Water injection dredging is used to do some dredging to level of ports, estuaries and channels as well as for development and maintenance of waterways. It put back there in suspension, creation of density current and transportation by current. It represents a very interesting alternative in relation to conventional methods (Borst *et al*., 1994; Sullivan, 1999; Murray *et al*., 1999). Several authors (Sutherland, 1966 ; Mutlu and Oguz, 1978; Perigaud, 1983) gave a very interesting formulation concerning extraction of burst in channel submitted to a horizontal out-flow binding hydraulic parameters to breaking conditions. Constraints formulation led in sediments layer by small disruptions leads to conditions for which criteria of Coulomb is verified of where rupture in block (Parsons, 1981; Moghadasi *et al*., 2004; Tigh and Byrne, 2004). Of others analyzed various parameters implied under hydrodynamics action (Migniot, 1968; Sleath, 1976; Yamatomo, 1977; Madsen, 1978; Perigaud, 1984, Migniot, 1989).

We intend to destabilize massif of deposit to put back sediments in suspension and to evacuate them by bottom outlet. Process consists in injecting a water flow (Qi) to Pressure (Pi) and speed (Vi) given by slant of diameter (Φi) driven in massif of sediments to depth (Hi) and distance (di). Flow is accompanied with a strength resulting from several efforts in presence. Movement of water injected entails a modification of interstitial pressure that applies on skeleton. Additional effective constraints are induced resulting in a going beyond of resistance of material. Zones of rupture are formed and are propagated until reaching surface of the massif. Particles are destabilized. Horizontal current provoked by opening of bottom floodgate acts then like a flushing.

Soil state is modified to every instant and therefore, it is dynamic whereas the models are static. We stumble then on this contradiction: to value the action of the throw one needs the stress and pressures, but one calculates them to fixed geometry, whereas the geometry of the material is variable because of internal erosion that occurs of where variation of the porosity and the permeability. Then, we apply explicitly that out-flow doesn't act on the material.

Also, cohesion of thin materials is result of attractions between molecules that essentially depend on the distance separating them. Therefore, particles spacing is a major factor influencing on silt properties. Void ratio represents, on the whole, spacing between particles of cohesionless material but for silt different spatial particles orientations can correspond to the same void ratio. So there is not a direct relation between void ratio and distance between particles. A priori, we don't have parameters of control to be able to determine accurately the moment to begin process.

MATERIALS AND METHODS

We suppose that mean is porous, isotropic, elastic, saturated and propertied Coulomb rupture criteria. Water flow injected is governed by Darcy law. Liquid phase is considered solely on a quantitative plan. Chemical aspect is disregarded. Numeric way supposes to have a tool of calculation coupling flow simulation the one of erosion and distortion resulting from double action of injection and horizontal out-flow. Also, uncertainty that carry weight on deposit and erosion laws (Cormaut, 1971; Owen, 1971; Bonnefille, 1975; Migniot, 1975; Lambermont and Lebon, 1978; Ariathuriai and Arulanadan, 1978; Kelly *et al*., 1979) and consolidation (Partheniades, 1965; Mignot, 1989) give use of mathematical models very hazardous. We raised difficulties to seize deposition stress strain law and consequences that ensue some for their modelling. Mathematical modelling sets in motion a multidisciplinary approach. That involves doing knowledge deepened of treated physical phenomenon, its state variables and laws that join its variables between them. It requires handling tools conceptual expressing these laws by a solid system of relations. A particular effort on initial and boundary conditions must be also expanded in order to restore physically admissible models. Of this fact, we adopted simplified formulation of injection with modelling hydromechanics behaviour of injected massifs. Gotten equations are solved by finite element completed by an experimental study. Effect of flushing transverse out-flow is disregarded. It will be put in evidence by tests.

RESULTS AND DISCUSSION

Experiences were conducted in a special glass box of 2 m70 long, 1 m2à wide and 0.60 m deep, digital flowmeter an electromechanical floodgate, injector and pump to variable debit (Fig. 1). Injector is positioned to wanted point; depth (Hi): 1/3Hs10cm; 2/3 Hs20 and distance (di): 10, 20, 30, 40, 50cm. Hydraulics parameters Pressure (Pi) and speed (Vi) are adjusted via device. Injection speeds varies between 0.10 and 2.5 ms^{-1}. Two pressures to entry are used: 2.2 m and 5.7 m.The flow is, every time, established upstream by electronic measure flowmeter and manual control. Losses in the system remain stationary, we can admit hypothesis that injected debit is constant. This hypothesis is verified by efficient exploratory tests.

Grains of sediments are submitted to forces of volume acting in sense opposed to the gravity. During experimentation cone and breaking circular lines around injector are formed (Fig. 2 and 3) It occurs in material one or several phenomena (distortion, fracture) driving to a change of form.

Volume evolution curves recovered according to the distance of injection have been gotten for several speeds. They display a general pace represented by a fast rise with a parabolic growth of all curves where the peaks

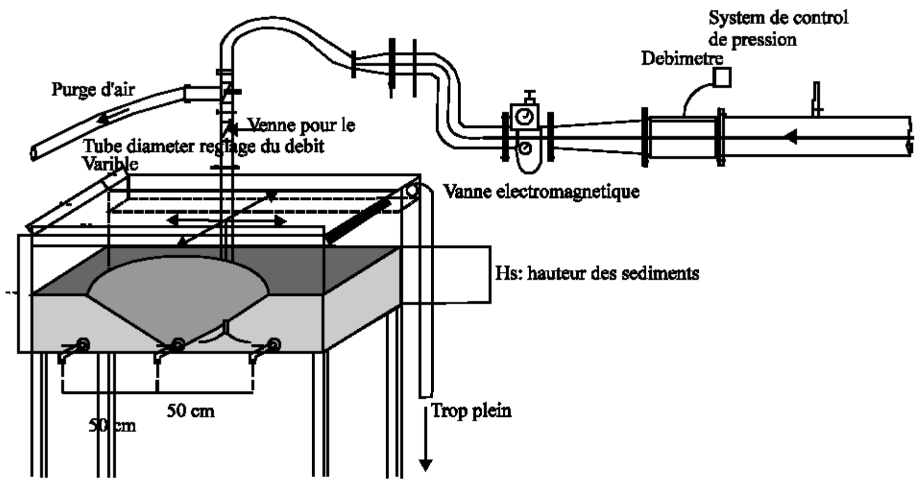

Fig. 1: Experimental device

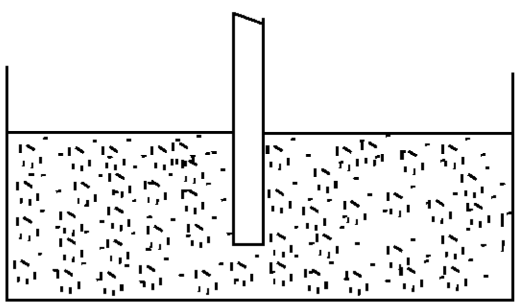

Fig. 2: Initial state

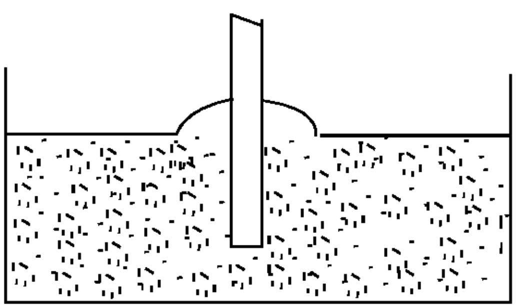

Fig. 3: Change of shape before rupture

don't seem predominant. Maximum is reached between 30 cm and 40 cm followed of a decrease to reach minimal values to mid-distance. Injection distance doesn't have any influence outside of zone influenced by effect of partition between 0 and 20 cm; what is logical. In same way for depth of injection tests showed that optimal value of Hi is located to 2/3 of Height of Sediments (Hs). Beyond this value lines of current would cut surface of bottom. Field of flow influence is decreased of where reduction area ruptures (Fig. 4-7).

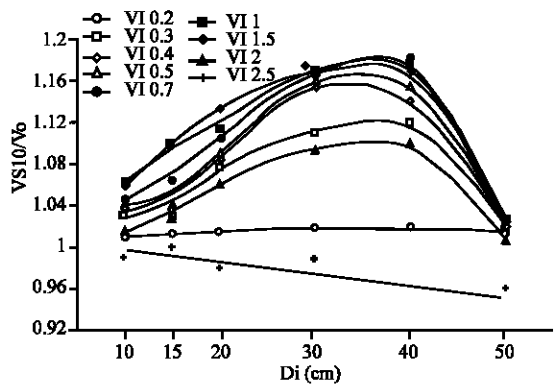

Fig. 4: Volume recovered according to distance of injection , Pi = 2 .2, Hi = 10

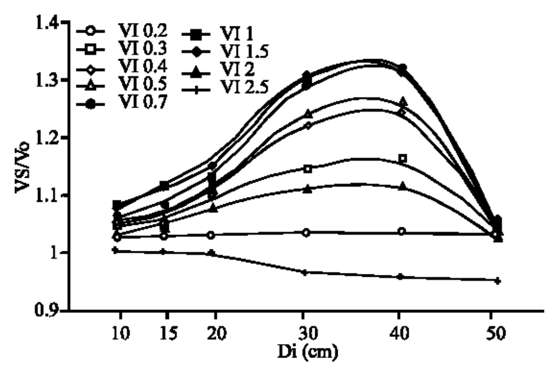

Fig. 5: Volume recovered according to distance of injection Pi = 2 .2, Hi = 20

It is valid for all trial parameters; there is only the percentage of gain that changes. Maxima values are given in Table 1.

It seems to be with time in interrelationship of Tr rupture that is inversely proportional with the speed of

Table 1: Recovered maximum volume

Depth		
Pressure	Hi20	Hi10
P22	1.33	1.18
P57	1.103	1.0554

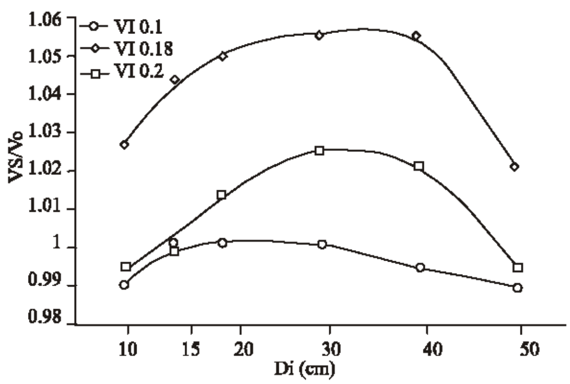

Fig. 6: Volume recovered according to distance of injection Pi = 5 .7, Hi = 10

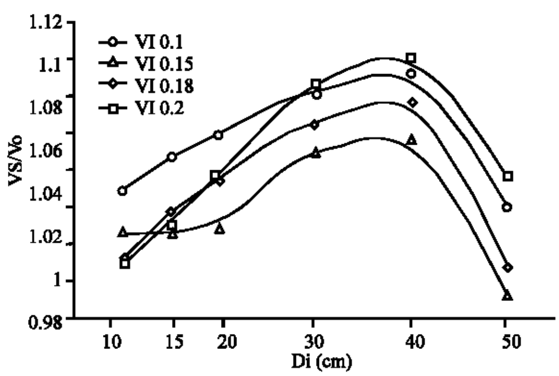

Fig. 7: Volume recovered according to distance of injection Pi = 5.7, Hi = 20

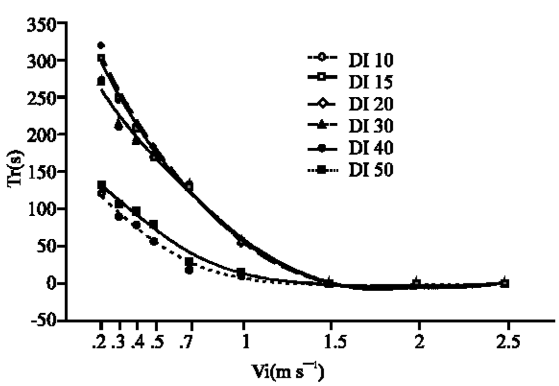

Fig. 8: Time of rupture according to the injection Pi = 2 .2, Hi = 10

injection (Fig. 8-11).We noted that more the time of rupture is weak more the zone of rupture is reduced. The

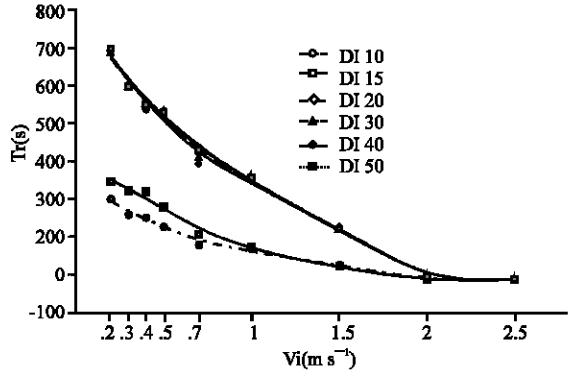

Fig. 9: Time of rupture according to speed of injection speed Pi = 5 .7, Hi = 10

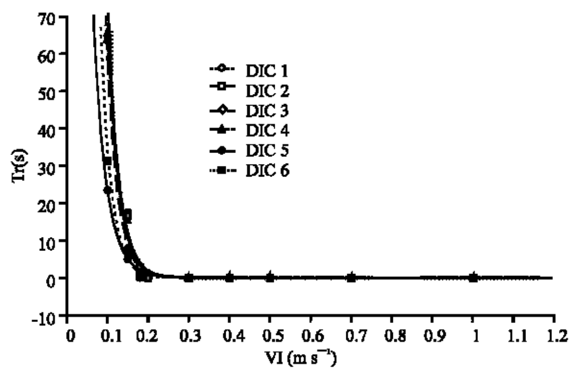

Fig. 10: Time of rupture according to injection speed Pi = 2.2, Hi = 20

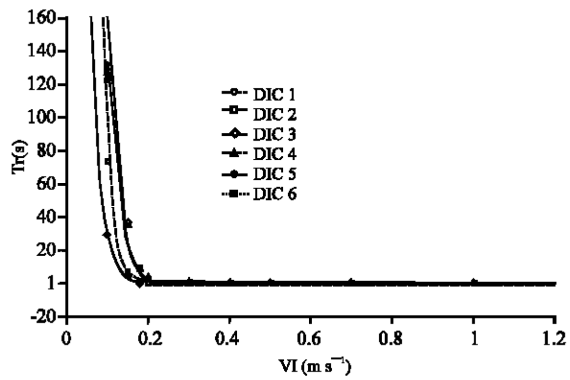

Fig. 11: Time of rupture according to injection speed, Pi =5. 7, Hi = 20

action of the injection didn't take place. The mobilized volume is reduced then.

Below and beyond some values of pressure and speed, injection doesn't act anymore. Values limits are said critical. P1 pressure constitutes the lower limit with a large range of action. For the superior limit, P2 domain of action is reduced more. Table 2 gives rupture time limits and speed of injection values.

Table 2: Values limit

Hi		Pi22	Pi57
Hi20	Tr min	682.7–0	131-0
	Vi m s^{-1}	0.2–2.5	0.1-0.2
Hi10	Tr min	318-0	65.4–0
	Vi m s^{-1}	0.2–1.5	0.1–0.2

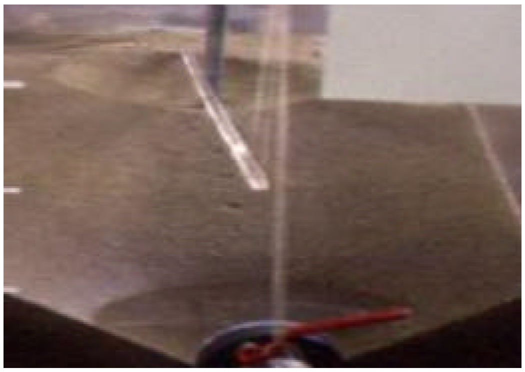

Fig. 12: Imprinted gotten in time of hopeless rupture

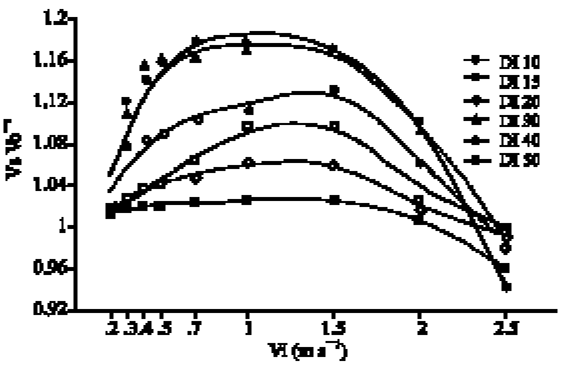

Fig. 13: Volume recovered according to to injection speed of Pi = 2 .2, Hi = 10

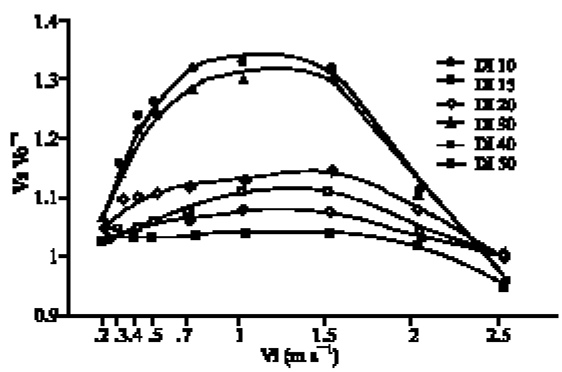

Fig. 14: Volume recovered according injection speed Pi = 2. 2, Hi= 20

When rupture time is hopeless, it forms pothole (Fig. 12). Area rupture localizes to tip and around injector; extent area rupture, is insignificant.

Table 3: Comparative values Vexp–Vtheo- Di = 30 cm

	0.4	0.5	0.7	1	1.5
Vol.exp.	1.22	1.243	1.287	1.302	1.306
Vol.theor	1.017	1.035	1.064	1.09	1.08
Ve/Vt	1.20	1.20	1.21	1.19	1.21

Table 4: Comparative values Vexp–Vtheo- Di = 40 cm

Vi	0.4	0.5	0.7	1	1.5
Vol.exp.	1.243	1.263	1.324	1.331	1.32
Vol.theor	1.03	1.05	1.1	1.12	1.13
Ve/Vt	1.21	1.20	1.20	1.19	1.17

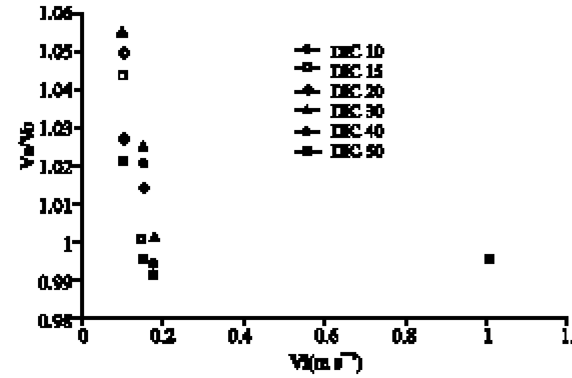

Fig. 15: Volume recovered according to injection speed Pi = 5. 7, Hi = 10

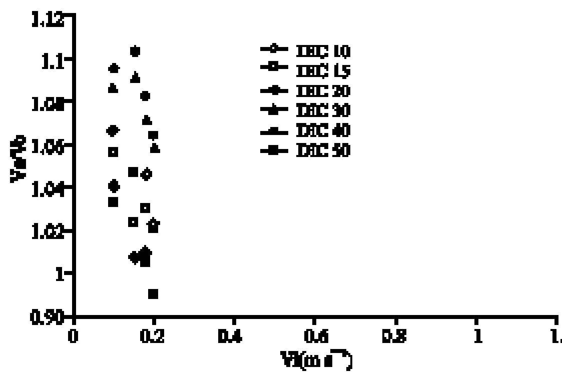

Fig. 16: Volume recovered according to injection speed Pi = 5 .7, Hi= 20

Consequently, the critical conditions appear as conditions limits permitting to get a maximal efficiency while minimizing injection energy. We present (Fig.13-16) the volume recovered according to the speed of injection below;

We deduct that it is couple (Pi, Vi) is predominant. An optimal surface exists according to two parameters. Figure 17 show that an optimal zone being located included speed between 0.5 and 1.5 m s^{-1} and a distance understood between 25 and 40 cm.

Table 3 and 4 gives values gotten by tests (Vexp) and those valued by numeric approach (Vtheo) for optimal conditions represented by Fig. 17. Difference is of 20%.

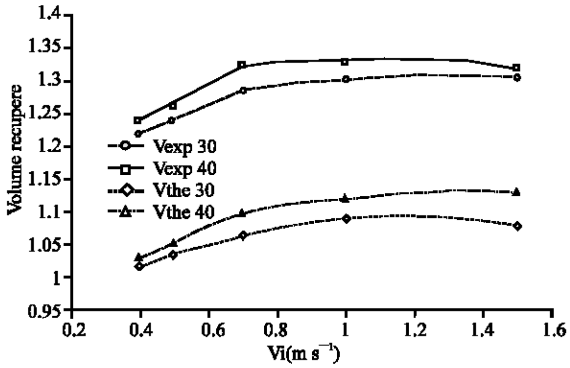

Fig. 17: Comparison of the experimental and theoretical values

Difference is due to horizontal current action when opening bottom outlet. Effect of flushing has not been taken into account in numeric equations. Figure 17 displays that the ratio is practically steady, approximately equal 20%.

CONCLUSION

We are providing some indications technologically interesting on the efficiency of desilting by injection while putting in evidence the preponderance of the couple "pressure-speed" as well as the existence of critical values for these parameters. Recuperation performances of volume reservoir depend on essential manner of this couple. While adopting like criteria of efficiency the energy, it is advantageous to operate to low pressure and speed. It allows us to consider inside a propertied setting a certain consistency and by there of to understand mechanisms. First practical forecasting is the one of the efficiency size order of a method used. Such a model rather appears like a physical reflection tool on the basis of minimal hypothesis and providing the approached value. It permits to classify the phenomena and to causes some questions to which one would not wonder necessarily.

REFERENCES

Ariathuriai, R., K. Arulanadan, 1978. Erosion rates of cohesive soils. J. Hydraulics Division, 104: 279-283.

Bonnefille, R., 1975. Simulation of deposit mud. 16th Congress. International Association of Hydraulic Research, Sao Paulo.

Borst, W.G. *et al*., 1994. Monitoring of water injection dredging, Dredging polluted sediment. Proceeding of the 2nd International Conference on Dredging and Dredged Material Placement, Part V2 Lake Buena Vista, L, USA., pp: 896-905.

Cravero, J.M. Guichon, 1989. Reservoir operation and solids transport. La Houille Blanche 3/4, pp: 292-295.

Cormaut, P., 1971. Experimental determination of solid flow rate of erosion fine sediment. 14th Congress International Association of Hydraulic Research, Paris.

Kelly, W., R.C. Gularte; V.A. Nacci, 1979. Erosion of cohesive sediments as rate process. J. Geotechnical Eng. Division, ASCE., 105: 673-676.

Kassoul, M., A. Abdelgader and M. Belorgey, 1997. Characterization of sedimentation in Algeria dams. Revue des Sciences de l'eau, 10: 339-358.

Lambermont, J. and G. Lebon, 1978. Erosion of cohesive soil. J. Hydraulic Res., 16: 27-44.

Madsen, O.S., 1978. Wave induced pore pressure and effective stress on a porous media bed. Geotechnique, 28: 377-393.

Migniot, C., 1968. Study of physics property of different typical sediment and their behaviour under hydrodynamics. La Houille blanche, 1: 591- 620.

Migniot, C., 1977. Action of currents, swell and wind on the sediments. La Houille action Blanche, 1: 9-47.

Mignot, C., 1989. Bending-down and rheology of mud. Part I. La Houille blanche, 1: 11-29.

Mogadashi, J.H. *et al*., 2004. Theoretical and experimental study of particle movement and deposition in porous media during water injection. J. Petroleum Sci. Eng., 43: 163-181.

Murray, L.A. *et al*., 1999. Hydrodynamic dredging: Principles, effects and methods, working group on Sea-Based Activities (SEBA), Hamburg, Germany.

National agency of hydraulics resources, Algeria (NAHR), 2004. Situation and need of development concerning irrigation and drainage in Algeria, pp: 92.

Owen, M., 1971. Siltation of fine sediments in estuaries. 14th congress, International Association of Hydraulic Research, Paris, D1.

Partheniades, E. 1965. Erosion and deposition of cohesive soils. J. Hydraulics Division, HY1, 91: 105-137.

Perigaud, C., 1984. Erosion of cohesive sediments by a turbulent flow, part 2: High concentration. J. de mécanique théorique et appliquée, 3: 505-519.

Parsons, J. 1981. Mud mobility. La technique de l'eau et de l'assainissement, 414/415: 43-47.

Perigaud, C., 1983. Mechanic of mud erosion. La Houille blanche, 7/8: 501-512.

Mutlu Sumer B. and B. Oguz, 1978. Particle Motions Near the bottom in turbulent flow in open chanel. Journal of Fluid Mechanic, 86: 109-127.

Sullivan, N. 1999. The Use of Agitation Dredging, Water Injection Dredging and Sidecasting: Results of a Survey Ports in England and Wales, Working group on Sea-Based Activities (SEBA) Hamburg, Germany.

Sutherland, A., 1966. Entrainment of fine sediments by turbulent flows. Phd thesis MIT.

Sleath, J.F., 1976. Force on a rough bed in oscillatory flow. JHR., 14: 146 154.

Tigh, E. and P.M. Byrne, 2004. Liquefaction flow of submarine slopes under partially undrained conditions: An effective stress approach. Revue canadienne de géotechnique, 41: 154-165.

UDNP, 2005. Report, Algeria, pp: 85.

Yamatomo, T., 1977. Wave induced instability in seabed. Symposium on coastal sediments, Charleston, pp: 898-913.