THE PERFORMANCE OF BATCH STABILIZATION RESERVOIRS FOR WASTEWATER TREATMENT, STORAGE AND REUSE IN ISRAEL

Marcelo Juanico

Juanico and Fredler Mediterranean Sewage Treatment and Storage Process Design Consulting, Ram On, M.P. Megido 19205, Israel

ABSTRACT

Stabilization reservoirs receive partially treated wastewater effluents for storage and controlled release. They are used in Israel for two purposes: a) to upgrade the quality of the effluents during the long residence time within the reservoirs and, b) to store the effluents during the rainy winter in order to perform agricultural irrigation during the dry summer. The improvement obtained in the quality of the effluents (i.e., the treatment capacity of the reservoirs) depends on the operational regime of the reservoirs as reactors: continuous flow, in series, batch, etc. The performance of the reservoirs as batch reactors for wastewater treatment is herein analyzed based on outdoor experiments carried out in real scale reservoirs with different hydraulic and organic loadings. The results of the experiments are compared with forecasts obtained through statistical and kinetic models. Stabilization reservoirs working in batch mode, when properly designed and operated, are able to remove COD, BOD, TSS and detergents by up to one order of magnitude, and Faecal coliforms by up to five orders of magnitude (before chlorination). A significant removal of heavy metals, bacteriophages and other pollutants is also obtained. The quality of the effluents released from the reservoirs, added to the capability for controlled release, permits both wide crop rotation and easy management of irrigation. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

KEYWORDS

Controlled discharge; sewage treatment; wastewater storage; warm regions; wastewater irrigation.

INTRODUCTION

Stabilization reservoirs are used in Israel for two purposes: a) to store partially treated wastewater effluents during long periods in order to discharge them in a particular time of the year and under controlled optimal conditions, and b) to upgrade the quality of these effluents during its long residence time within the reservoirs. The need for controlled discharge derives from the ‘rainy winter - dry summer’ climate of the Mediterranean region which demands large volumes of water for irrigation during the summer. In some cases wastewater is stored in the reservoirs during the hot summer when beach resorts are full, for discharge to the sea or lakes during the winter when beach resorts are empty. When effluent is discharged into rivers, the reservoirs provide storage when the rivers have minimum flow (dry season, or ice cover season) in order to discharge when flow and dilution are maximum. In other cases the winter stored effluents can be used to maintain a minimum flow in the rivers during the dry season when many of them become dry beds; the quality of the effluents must meet the river ecosystem needs in this situation. The need to upgrade the quality of the effluents derives from the more and more complex mixture of pollutants contained in modern sewage (Juanico, 1994a), the increasing concern about environmental protection, the periodic failures of intensive sewage treatment plants such as activated sludge, and the standards of wastewater quality required for wastewater irrigation.
The first stabilization reservoirs were constructed in Israel in the early '70 (Pano, 1975) and more than 130 of them are in operation today. Storage capacities vary from 50,000 to 6 million m$^3$ and depths from 5.5 to 15 m. The primary purpose of the reservoirs was merely the seasonal storage, but soon the extra treatment that the storage adds to wastewater became clear.

Stabilization reservoirs can be operated in many different basic forms: single continuous flow, continuous flow in series, sequential batch in parallel or in series, quasi-sequential batch, and many combinations of the basic forms. The operational regime determines the performance of the reservoir in terms of treatment capacity, outflow volumes, organic loading and oxygen regime, etc. This paper describes the performance of stabilization reservoirs as wastewater treatment units when operated as batch reactors. The analysis is based on both experiments with real-scale reservoirs and simulation models.

ANTECEDENTS

Field Work on Real-Scale Wastewater Storage Reservoirs in Israel

The first experiments with batch operated wastewater storage reservoirs were performed in Israel 20 years ago by Kott (1975). The first experiments with continuous flow reservoirs are described by Pano (1975), Berend and Pano (1976), Eren (1975, 1976, and 1978) and Burstein (1979). Priority was given to the construction of single continuous flow reservoirs in the seventies when large amounts of low quality effluents were necessary for cotton irrigation, but priority switched to reservoirs in series and batch operated when effluents of higher quality were required for alternative crops in the late eighties. More detailed studies were later reported on the performance of different kinds of reservoirs (pollutants removal, variability of outflow quality, hydraulic and organic loadings, etc.) and many aspects of their limnology (stratification, oxygen regime, plankton community, etc.) by Abeliovich (1982), Lokieck (1983), Eren and Dor (1985,1986), Dor (1987), Dor et al. (1987), Juanico and Shelef (1991, 1994), Aharoni and Kanarek (1994) and Juanico (1994c and submitted). The removal of Total and Faecal coliforms, E. coli, Salmonella, Faecal streptococcus, bacteriophages and enteroviruses was studied in Israel by several authors, in reservoirs operated under many different regimes (Kott, 1975; Perle, 1988; Liran, 1990; Fattal et al., 1993; Liran et al., 1994; Goldberg, 1994 and others). The effect of chlorination has been addressed by Kott et al. (1978) and Rabkin and Eren (1982). Abeliovich (1987) and Abeliovich and Vonshak (1993) started the analysis of nitrification in these reservoirs. Dor and Raber (1990) addressed some aspects of reservoir monitoring and Furter et al. (1993) started the development of remote-sensing devices for monitoring purposes. Avnimelech and Wodka (1988) have analyzed sedimentation and the digestion of sediments. The removal of heavy metals was studied by Juanico et al. (1995). Argaman et al. (1988) performed the first detailed study on the hydraulic flow pattern of two reservoirs using Rhodamine B as a tracer, showing that they perform as perfectly mixed reactors. Juanico and Friedler (1994) developed the mathematical tools and computer algorithms to analyze the hydraulic age distribution of the effluents within the reservoirs. The role of stabilization reservoirs as integral parts of modern sewage treatment and storage systems has been discussed by Juanico (1994a, 1994b).

Modelling

Juanico and Shelef (1991, 1994) developed multiple regression models for the forecasting of BOD and COD removal in stabilization reservoirs under the Israeli climatic conditions. Liran (1990) established the basis for both multiple regression and kinetic models for bacterial die-off. A kinetic model for E. coli die-off was later developed by Goldberg (1994). Liran's and Goldgerg's models are based on totally different sets of data from different reservoirs, handled and analyzed by different methodologies, but give very similar outputs. A model of the digestion of sediments at the bottom was developed by Avnimelech (1989). The work of Juanico and Friedler (1994) includes a general model of the hydraulic age distribution of the effluents within the reservoir. All these models are based on the previously quoted field work on real-scale reservoirs. The accumulated experience and information were finally elaborated by Friedler
(1993) in a new mathematical kinetic meta-model (SRES - Stabilization Reservoirs Ecological Simulation) which combines classic lake modelling tools with sewage treatment ones. The SRES model is able to simulate the interactions between all main hydraulic, hydrological, physico-chemical and biological processes, forecasting the performance of the reservoir and the quality of the effluents as a function of more than 30 design and operational parameters. Several new models have been developed in that last years, still unpublished.

THE PERFORMANCE OF BATCH OPERATED RESERVOIRS

Case Study I: a shallow reservoir, batch operation during winter; Data from Kott (1975) and Kott et al. (1978).

The reservoir 'Yagur' is 3.5 m deep with an active volume of 70,000 m³. In the experiment herein described the reservoir was filled with effluents from the trickling filter sewage treatment plant of the city of Haifa. Input of effluents to the reservoir was stopped on November 27 (early winter) and the reservoir was then operated in batch mode during 73 days. Samples were taken from four depths (10 cm, 50 cm 150 cm and 350 cm) from two opposite sides of the reservoir, approximately once a week, and analyzed for several physico-chemical and bacteriological parameters. Figure 1 presents the mean values (from all the depths), at one of the sampling points (samples from both points rendered similar results), for Faecal coliforms and human enteric viruses. It can be observed that Faecal coliforms numbers dropped by two and a half orders of magnitude during the first 10-15 days, then remained unchanged during about one month, to have a new reduction after another two weeks. The latest increase in F. coliforms numbers may be due to bird drops or another external contamination. Human enteric viruses presented a similar pattern but without the latest 'increase', reaching zero concentration after 60-70 days of batch operation.

![Figure 1. Reduction in the Number of Human Enteric Viruses and Faecal Coliforms in the Yagur Reservoir Operated as a Batch Reactor in Winter. Mean of all Depths. Data from Kott (1975) and Kott et al. (1978)](image-url)
Case Study II: a deep reservoir, batch operation during winter.

The 'Sarid' reservoir is 7.3 m deep with an active volume of 405,000 m³. It receives effluents from the city of Afula after treatment in stabilization ponds (which are overloaded). Input of effluents to the reservoir was stopped on November 30 (early winter) and the reservoir was then operated in batch mode for several months. Composite samples from several points and depths were taken on November 1st (when effluents were still entering to the reservoir), March 1st (after three months of batch operation) and on April 12 (after more than four months of batch operation), and analyzed for several physico-chemical and bacteriological parameters. The reduction of BOD and Faecal coliforms in the reservoir were simulated by mathematical and statistical models. The values for BOD and Faecal coliforms in the reservoir, comparing predicted with actual values are presented in Figure 2. It can be observed that Faecal coliforms numbers dropped by four and a half orders of magnitude in about 90 days. The latest sample taken on April also showed an almost zero concentration of Faecal coliforms. BOD concentration was reduced till reaching a minimum of 10-20 mg/L. In both cases the predictions of the models were more conservative than the measured values.

Figure 2. Reduction of BOD and Faecal Coliforms in the Sarid Reservoir Operated as a Batch Reactor in Winter. Composite Samples from Various Points and Depths. Lines: Model Forecasting. Stars: Measured Values.

Case Study III: two deep reservoirs in series, batch operation during spring.

The reservoir 'HaMeshutaf' is 8 m deep with an active volume of 850,000 m³; the reservoir 'III' is 6 m deep with an active volume of 400,000 m³ (Fig. 3). The reservoir 'HaMeshutaf' receives about 3,300 m³/day of raw sewage from the town of Migdal HaEmeq with a BOD of about 1000 mg/L (it contains discharges from food industry). Some of the effluents from the 'HaMeshutaf' reservoir with a BOD of about 250 mg/L and Faecal coliforms of about 2E5 pass to the 'III' reservoir. During the studied year, the 'III' reservoir had 50,000 m³ of effluents by the end of January, received 211,000 m³ of effluents during
February, 105,000 m³ during March, and 21,000 m³ till April 14. On April 14 all input of wastewater to the reservoir 'III' was stoped and it worked as a batch reactor. Samples were taken at the East and West sides of the reservoir, at surface (0.2 m below surface) and bottom (0.5 m above bottom) and analyzed for several parameters. Profiles of temperature, pH, dissolved oxygen, electrical conductivity and light penetration were also taken. The results of BOD and Faecal coliforms analyses, compared with model predictions for surface data are presented in Figure 4. The BOD model is a multiple regression one described in Juanico and Shelef (1991, 1994). The Faecal coliforms model is a simple kinetic one.

Figures 3 and 4 show that, after a batch operation of about 45 days, the 'III' reservoir produced effluents of unrestricted irrigation quality even for rigorous standards. The results also show that two reservoirs in series have, besides their storage capacity, a high treatment capacity, reducing BOD from 1000 to 10 mg/L. However, the 'HaMeshutaf' reservoir is a serious source of malodours. High loaded anaerobic reservoirs are not recommended except when they are far away from any populated area. The models succeded to predic fairly well the BOD degradation and Faecal coliforms die-off processes and can be used as design tools under the Mediterranean conditions. The design under different climatic conditions requires more sophisticated models such as the SRES one.

**BASIC OPERATIONAL REGIMES**

Continuous or discontinuous input of wastewater to the reservoir, and continuous or discontinuous discharge of effluents from the reservoir, are two main operational parameters affecting general performance. Figure 5 describes some basic operational regimes combining different input and discharge possibilities (there are many more alternatives than the few showed in Figure 5. Continuous flow (or continuous input) regimes (reservoirs # 1,7,8,9) receive wastewater all the year round. Sequential batch regimes are operated in such a way that wastewater is also received by the system all the year round, but the reservoir which releases effluents stops to receive wastewater before its outlet is opened. In the quasi-sequential batch regime (# 2,3) the input of wastewater to the reservoir is stoped simultaneously with the opening of the outlet. In the sequential batch in series regimes, the input may enter always to the same reservoirs of the series (# 10) or alternatively to both of them (# 12,13).

Different discharge curves are typical of different situations (Fig. 6). For example, horticulture irrigation in arid zones may have an almost homogeneous demand of water all the year round. Semi-arid regions such as those of Mediterranean climate, are characterized by a rainy winter and a dry summer. Under the-
se conditions, golf course irrigation may demand water all the year round but much more intensively during the summer. Some fruit trees may need water during the spring-summer-fall but not in winter. Under the same conditions, quick growing crops such as cotton may need water only during a short summer irrigation season. Wastewater storage reservoirs constructed to avoid the discharge of effluents to the sea, lakes or rivers during some periods of the year may also have a short discharge season. The curve of the discharge of effluents deeply affects the selection of the operational regime of the reservoirs.

THE EFFECT OF THE OPERATIONAL REGIMES

Sequential batch reservoirs, either in parallel or in series (# 11, Fig. 7) perform the best as treatment units. They are able to remove BOD, COD, detergents and other low-decay constant pollutants by up to one order of magnitude, and Faecal coliforms and other high-decay constant pollutants by up to five orders of magnitude. The input of wastewater to the reservoir is closed before the outlet is opened. Thus, the re-
reservoir releases effluents of good quality during the whole discharge season. Sequential batch reservoirs in series are more economic than sequential batch in parallel when discharge is seasonal. In type I operation (Fig. 5) the second reservoir of the series never receives wastewater directly but always through the first reservoir; this renders very good outflow quality, but the surface organic loading to the first reservoir may be too high in some cases. In the type II operation, organic loading is more evenly distributed between the two reservoirs. At least three reservoirs are required for an operation of sequential batch in parallel (#4,5,6; Fig. 5) and the system releases a relatively small amount of effluents in relation to the total size of the units; however, they perform the best as treatment units when release is required all the year round.
DISCHARGE (Shadowed area = 100% of annual discharge)

CONTINUOUS DISCHARGE, HOMOGENEOUS.
E.g., irrigation of horticulture in arid regions. Storage not necessary.
Maximum effluent quality: plug-flow maturation pond, or sequential batch reservoirs in parallel.

CONTINUOUS DISCHARGE WITH INTENSIVE DISCHARGE SEASON.
E.g., irrigation of golf courses in semi-arid regions.
Maximum effluent quality: sequential batch reservoirs in parallel.

DISCONTINUOUS DISCHARGE, LONG DISCHARGE SEASON.
E.g., irrigation of fruit trees in semi-arid regions.
Maximum effluent quality: sequential batch reservoirs in series.

DISCONTINUOUS DISCHARGE, SHORT DISCHARGE SEASON.
E.g., irrigation of cotton in semi-arid regions, or seasonal discharge to sea.
Maximum effluent quality: sequential batch reservoirs in series, or quasi-sequential batch reservoirs in parallel.

Figure 6. Some Typical Effluent Discharge Curves from Stabilization Reservoirs

When the release of effluents is almost homogeneous all the year round (upper discharge curve in Fig. 6) a plug-flow maturation pond may be a more economically feasible solution to obtain good outflow quality. However, a plug-flow maturation pond can not offer the same degree of reliability than a system of sequential batch reservoirs in parallel where outflow is taken always from an input-closed reservoir. Quasi-sequential batch reservoirs in parallel (#2; Fig. 7) are more economical than actual sequential batch and render very good results when the discharge season is very short (lowest discharge curve in Fig. 6).
REFERENCES


