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Flow rate of liquid cattle manure leakage into subsoil during storage

Jiří Vegricht*, **Josef Šimon**, **David Hájek**, **Jiří Bradna**

Research Institute of Agricultural Engineering, Prague, Czech Republic

**Corresponding author: jiri.vegricht@vuzt.cz*

Abstract

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Under laboratory conditions, seepage of liquid cattle manure with dry matter content of 3–8% through subsoil was studied in relation to its dry matter content and period of storage. Statistical dependence of the total amount of eluate on the dry matter has been found ($P = 0.0013$). A hypothesis was also confirmed that liquid cattle manure shows a sealing effect during storage. It was found that the average value of coefficient of permeability decreases as soon as 48 hours after the start of storage under the value 5.56171×10^{-6} cm·s^{-1}, which, according to peer reviewed literature, is not hazardous to the environment. The results will help in designing projects of liquid cattle manure reservoirs and assessment of their effect on the environment.

Keywords: manure storage; sealing effect; coefficient of permeability

In the Czech Republic, liquid cattle manure is stored mainly in free standing or partly recessed vertical storage tanks with a height up to 10 m. These storage facilities have mostly circular of rectangular shape and the construction material is reinforced concrete or steel sheet with protection against corrosive effects of liquid cattle manure. To a lesser extent, earth foil reservoirs are also used for storage of liquid cattle manure. The bottom of tower storage facilities is formed by a layer of reinforced concrete. These reservoirs are designed to prevent the leakage of liquid cattle manure into subsoil and groundwater contamination.

Jetel (1982) classifies substrate permeability, expressed by the filtration coefficient, into eight classes. Substrates with a filtration coefficient under 1×10^{-8} m·s^{-1} are considered to be almost impermeable (Ševčík 2004). Such a filtration coefficient value is reported for example for clay (Geotechdata.info 2013).

The Czech legislation requires regular inspections of all storage facilities of liquid cattle manure in order to discover eventual leakage in time. For this purpose, leakage control systems (drainage) are placed under the reservoir and drained to inspection wells.

Therefore, it is necessary to better understand the process of leakage of liquid cattle manure into subsoil during storage. It is mainly necessary to analyse the seepage quantity of liquid cattle manure that penetrates into the subsoil and the dynamics of this penetration during storage.

It has been documented in scientific literature that during storage of liquid cattle manure a layer of organic sludge, which forms at the bottom of a reservoir, has a sealing effect and gradually

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decreases the leakage of manure into the subsoil (Glanville et al. 2001; Ham 2002; Cihan et al. 2006). As a consequence of this phenomenon, the leakage of liquid cattle manure decreases after a certain period of time to a value, which is no longer harmful from the viewpoint of groundwater protection (Barrington et al. 1987a; Ham 2002; Cihan et al. 2006).

Some studies even show that correctly designed storage facilities have a self-sealing ability (Fleming et al. 1999).

The objective of this work is to verify and confirm the hypothesis that during the storage of liquid cattle manure sedimentation of fine particles occurs, which gradually forms a sealing layer at the bottom of a reservoir; after some time, it reduces the leakage of liquid cattle manure into the subsoil to values that do not present any significant danger to the environment.

The performed tests were aimed at determining the penetration of liquid cattle manure with varying dry matter content into the soil and evaluation of the total quantity of liquid cattle manure that penetrates into the subsoil and the determination of dynamics of this process during storage period in dependence on the stored manure dry matter content.

The results will be used to specify the requirements for liquid cattle manure storage facilities and for monitoring of tightness during storage. Subsequently, these results will be used within the project and realization of storage facilities, legislation preparation and consultancy.

MATERIAL AND METHODS

The flow rate of a liquid through the saturated zone of solid porous body can be determined according to the Darcy's law (ČSN CEN ISO/TS 17892-11:2004, 2005 – Geotechnical investigation and testing – Laboratory testing of soil – Part 11).

Liquid cattle manure is a non-Newtonian liquid. For the purpose of determination of its seepage through the examined substrate, coefficient of permeability was found experimentally under chosen storage conditions:

$$k_{exp} = h \times t^{-1}$$

where: k_{exp} – coefficient of permeability (m·s^{-1}); h – height of liquid seeped through (m), t – seeping time (s)

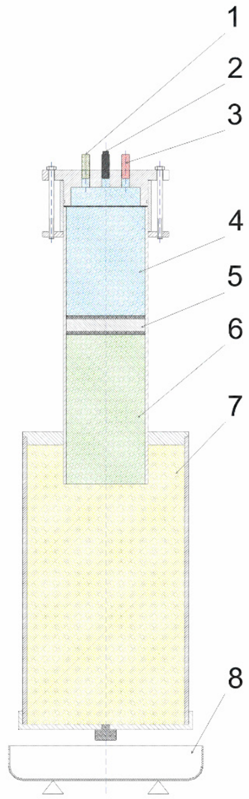

Fig. 1. Diagram of a device for measurement of liquid cattle manure seepage through soil
1 – ultrasonic scanner of distance, 2 – supply of compressed air, 3 – pressure sensor, 4 – compressed air, 5 – piston with a seal, 6 – filling of liquid cattle manure, 7 – soil substrate, 8 – receiving dish on scales

Regarding the sealing ability of liquid cattle manure, it can be expected that its coefficient of permeability will decrease significantly during storage, as suggested by the results published of many authors (Barrington et al. 1987; Ham 2002; Scully et al. 2006).

For the measurements of seepage of liquid cattle manure through soil, a device in Fig. 1 has been designed and tested.

This device consists of two coaxial superposed cylinders with diameters 150 mm and 300 mm. The smaller cylinder has two chambers separated by a movable sealed piston and extends 100 mm into the larger cylinder, which is filled by examined substrate.

The chamber No. 6 is filled with liquid cattle manure, which is pushed by the piston No. 5 by air overpressure supplied from compressor with automatic pressure regulation. In the lid of air chamber No. 4 there is a pressure sensor, which continuously monitors the pressure level in the chamber No. 4. The lid

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Table 1. Composition of used gravel sand (grain size 0–4 mm)

Fraction (mm)	over 4.0	4.0–2.8	2.8–2.0	2.0–1.0	1.0–0.5	0.5–0.2	under 0.2
(wt.%)	2.8	5.9	6.8	17.9	32.5	26.5	7.6

also includes an ultrasonic sensor, which monitors the movement of the piston No. 5 during the experiment.

Before each test, the substrate was loaded into the chamber No. 7 so that the upper level of substrate was 100 mm above the bottom rim of the inner cylinder. This arrangement was chosen with the aim to create conditions similar to the situation, in which a crack emerges in the jacket of a liquid cattle manure reservoir, while enabling leakage into the subsoil without limitation by obstacles

After filling chamber No. 7 with soil, chamber No. 6 is filled with a measured quantity of liquid cattle manure and the piston No. 5 is inserted. The piston has an air release valve for de-aeration of the manure chamber.

During the measurement, overpressure acts on the piston No. 5, which models the effect of depth in a storage tank. Then, the piston pushes the liquid cattle manure through the substrate. The piston travel is measured by ultrasonic distance measurement sensor No. 1 and recorded. Liquid cattle manure passed through the soil column (eluate) is collected in a dish No. 8, which is placed on a scale. All values (time, pressure, piston travel, quantity and weight of infiltrated and flowed liquid cattle manure) are recorded continuously into computer (sampling frequency was 60 h^{-1}). The obtained data were subsequently processed and evaluated in an Excel sheet and statistical software R (2005).

The experiments have been carried out with liquid cattle manure with dry matter content of 3–8%. Remaining feed and bedding residues were removed from the manure on a screen with 8 × 8 mm mesh.

As the model soil fluvial gravelly sand was chosen; it was fraction-sorted, twice washed with grain size of particles 0–4 mm, corresponding to the standard ČSN EN 12620+A1:2008, ČSN EN 13043:2004, ČSN EN 13139:2004, ČSN EN 13242+A1:2008 with average initial moisture of 3%.

The share of particular fractions is shown in Table 1. The average value of the used sand coefficient of permeability (saturated hydraulic conductivity), according to the Darcy´s law for water, was $3.3 \times 10^{-4} \pm 6.4 \times 10^{-5}$ $m \cdot s^{-1}$.

Average overpressure in a chamber was maintained by automatic regulation of compressor pressure at 90 ± 10 kPa. This corresponds to a depth in a liquid cattle manure reservoir of 9 ± 1 m.

Every experiment lasted a min, of 48 hours. In the course of measurement, the liquid manure was regularly replenished, as necessary, into the chamber No. 6.

The measurements were repeated at least three times at all dry matter contents of the examined manure, i.e. 3, 4.5, 6.5 and 8%, in order to evaluate the effect of dry matter on the seepage rate into the standardised sandy substrate.

RESULTS AND DISCUSSION

The permeability of liquid cattle manure measured by the quantity of eluate drained through the soil column into the dish in dependence on its dry matter content is shown in Fig. 2.

From the graph, it is obvious that the dynamics of permeability of manure through the sandy substrate has an introductory part when the sandy soil hydraulically saturates by liquid cattle manure. The seepage into the soil gradually decreases and after a certain time the sealing effect begins to manifest itself as a consequence of the formation of a filtration cake made by fine organic particles in the manure.

In the experimental set-up, this cake fills an area of an upside down mushroom shape, which corresponds to the supposed seepage path of liquid cattle manure in the soil. An example of this cake can be seen in Fig. 3.

After a short time, the leakage of liquid cattle manure into the subsoil practically ceases. Intensity of the leakage in all examined samples gradually equalizes and the effect of dry matter content on penetration (eluate) into the subsoil becomes insignificant after a certain time. After 48 h of leakage into the soil in the device, it is on average 0.001–0.008 $kg \cdot h^{-1}$, which corresponds to the average coefficient of permeability 3.93174×10^{-6} $cm \cdot s^{-1}$ (3.93174×10^{-8} $m \cdot s^{-1}$).

The total quantity of eluate depends on the dry matter content of the liquid manure. This is documented in the graph in Fig. 4, where the total quantity of eluate during the first 48 h is plotted. This

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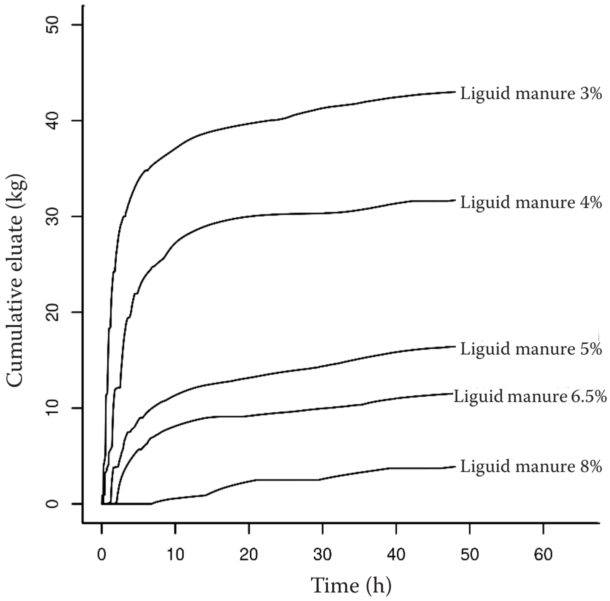

Fig. 2. Penetration of liquid cattle manure with varying dry matter content through the substrate with layer thickness of 600 mm

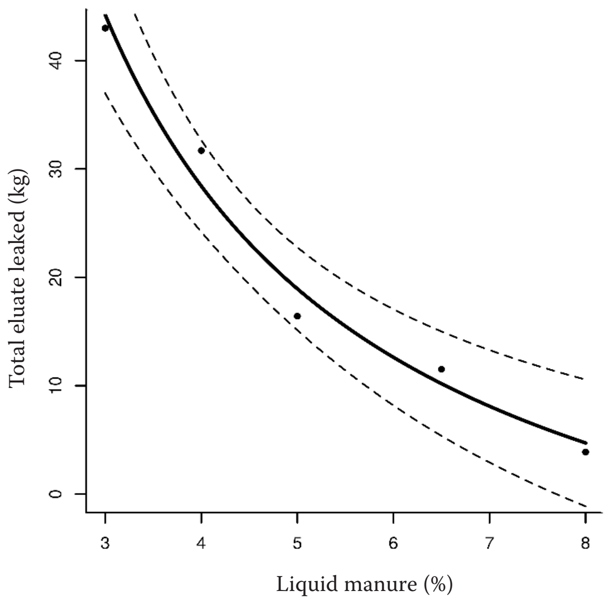

Fig. 4. Dependence of the total quantity of eluate released during the first 48 h of storage on dry matter content of liquid cattle manure (p = 0.0013)
black points denote the measured data and the solid line the estimated regression function with its 95% confidence bands (dashed lines)

dependency is hyperbolic and statistically significant (p = 0.0013).

It can be seen that the eluate flow rate is the highest at the beginning and it depends directly on the dry matter content. The highest eluate flow rate occurs at dry matter content of 3% and the lowest at dry matter content of 8%.

Fig. 5 shows dependence of time until maximum flow of eluate is reached (i.e. the substrate in chamber No. 7 is saturated and eluate begins to flow into the dish No. 8) on the dry matter content of manure. This dependence is exponential and statistically evidential (p = 0.007).

Fig. 3. The cake that is formed at the input of liquid cattle manure from the chamber No. 6 (Fig. 1) to the chamber No. 7 (Fig. 1), has the shape of a mushroom turned upside down and corresponds to the supposed seepage path of liquid cattle manure through the subsoil

As could be expected, liquid cattle manure with the lowest dry matter content begins to flow the most rapidly through the soil, because it has the lowest share of organic particles that retard its flow and are the cause of sealing properties.

After a certain period, the intensity of seepage decreases enough so that the difference between samples with different dry matter contents is insignificant as evidenced in Fig. 6.

In Fig. 6, time dependency of the threshold values of flow intensity is given. For any chosen value of the flow rate, the graph shows the measured moment; 95% of measurements lie under this value. This means, for example, that after ca 44 h the leakage intensity will be lower than 1×10^{-5} cm·s^{-1}. The estimated model is statistically significant, p is lower than 0.0001. The objective of this graph is to demonstrate that during storage, a considerable decrease in leakage of liquid cattle manure into the subsoil occurs and a sealing effect is achieved. It means that values are reached which are no longer harmful to the environment.

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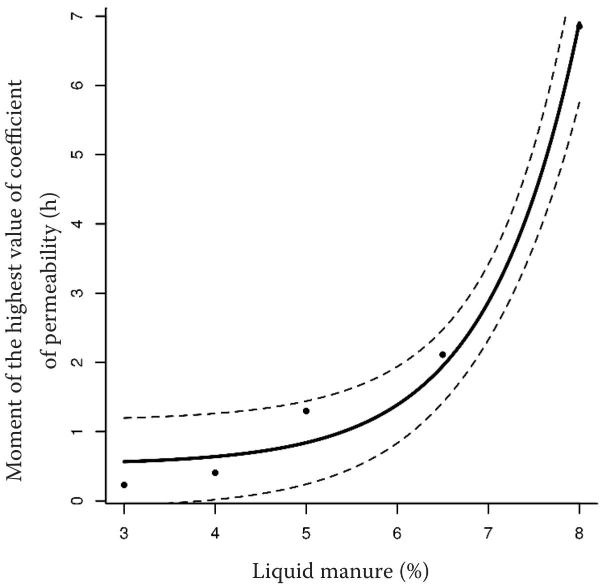

Fig. 5. Dependence of time of maximum eluate flow on dry matter content of liquid cattle manure (p = 0.007)
black points denote the measured data and the solid line the estimated regression function with its 95% confidence bands (dashed lines)

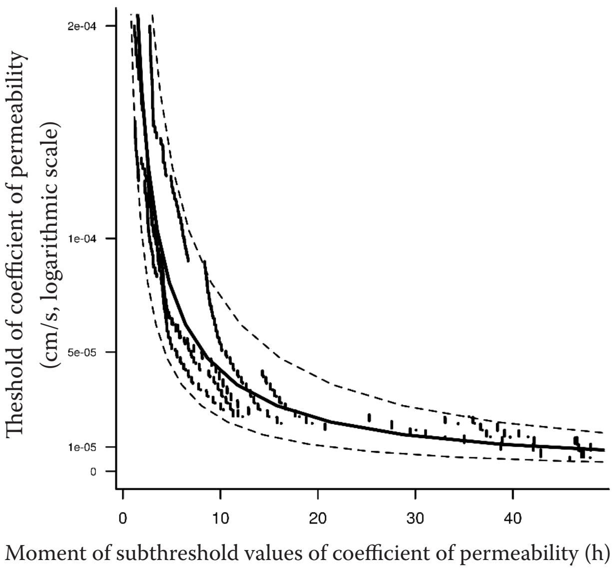

Fig. 6. Changes in a coefficient of permeability of liquid cattle manure in dependence on the period of storage. The graph shows all measurements of the coefficient of permeability of liquid cattle manure. From the graph, a significant dependence of a coefficient of permeability on storage period (p = 0.0001) is obvious as well as gradual minimization of the effect of manure dry matter content on the final value of the coefficient

Similar dependence of leakage rate of liquid cattle manure with solid content 2– 3.5% to sandy substrate is included in (Scully et al. 2006).

The results of this work agree with existing data in literature, which also mention that after a certain period of storage, the leakage of liquid cattle manure decreases to a value not harmful from the viewpoint of groundwater protection (Barrington et al. 1987a; Ham 2002; Cihan et al. 2006).

Fleming et al. (1999) in a literature review on liquid manure leaking during storage list the values of hydraulic conductivity of liquid manure from different authors in the range of 1×10^{-9} to 3×10^{-8} m·s^{-1}, which corresponds very well to the values measured herein.

CONCLUSION

Leakage of liquid cattle manure with dry matter content of 3–8% into the sandy soil was tested under laboratory conditions over a period of minimum 48 hours. The dynamics of this process was examined as well.

Sealing ability of the stored cattle manure was confirmed for sandy soil with coefficient of permeability 2.2–3.9 × 10^{-4} m·s^{-1}, which is unfavourable for the threat of leakage into groundwater.

Dynamics of liquid cattle manure leakage into the subsoil and the total quantity of eluate depend statistically significantly on the dry matter content of liquid cattle manure (p = 0.0013).

It was also proven that the gradual sealing of subsoil by fine particles of liquid cattle manure occurs early during storage. After only 48 hours of storage, the coefficient of permeability decreases considerably to values under 3.937×10^{-8}, which can be considered acceptable for groundwater protection based on scientific literature. The coefficient of permeability decreases to similar values in the course of storage period regardless of the dry matter content.

The obtained data are significant to assess the effect of storage facilities for liquid cattle manure on the environment and for their projecting and implementation.

References

Barrington S.F., Jutras P.J., Broughton R. S. (1987): The sealing of soils by manure I. Preliminary investigations. Canadian Agricultural Engineering, 29: 99–103.

https://doi.org/10.17221/109/2017-RAE

Barrington S. F., Jutras P. J., Broughton R. S. (1987a): The sealing of soils by manure II. Sealing mechanisms. Canadian Agricultural Engineering, 29: 105–108.

Cihan A., Tyner J.S., Wright W.C. (2006): Seal formation beneath animal waste holding ponds. Transactions of the ASABE, 49: 1539–1544. American Society of Agricultural and Biological Engineers.

Fleming R., Johnston J., Fraser H. (1999): Leaking of liquid manure storages. Literature Review. Ontario N0P 2C0: Ridgetown College – University of Guelph Ridgetown. Available at http://agrienvarchive.ca/res_papers/download/fleming_leakmanure.pdf

Geotechdata.info. Soil void ratio. Available at http://geotechdata.info/parameter/permeability.html

Glanville T.D., Baker J.L., Melvin S.W., Agua M.M. (2001): Measurement of leakage from earthen manure structures in Iowa. Transactions of the ASABE, 44: 1609–1616.

Ham J.M. (2002): Transactions of the ASAE, 45: 983–992. American Society of Agricultural Engineers.

Jetel J. (1982): Určování hydraulických parametrů hornin hydrodynamickými zkouškami ve vrtech. Praha, Academie.

Scully H., Gleeson T., Purcell P.J, O'Riordan E.G., Long M., Crosse S. (2006): An evaluation of earth-banked tanks for slurry storage. Beef Production Series No. 53, Grange Beef Research Centre Dunsany Co. Meath, Ireland. Available at http://t-stor.teagasc.ie/bitstream/11019/976/1/eopr-4679.pdf

Ševčík D. (2004): Propustnost závalového prostoru stěnového porubu. Sborník vědeckých prací Vysoké školy báňské – Technické univerzity Ostrava, Řada hornicko-geologická, L: 109–114.

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