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The Henry Samueli School of Engineering

ENVIRONMENTAL PROCESS LAB

EPL

Master Thesis in

Environmental Engineering

Oxygen mass transfer in a bubble column with non-Newtonian fluids

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ABSTRACT

Every community produces both liquid and solid wastes and air emissions.

The term wastewater refers to water that has been adversely affected in quality by any anthropogenic influence (human waste, septic tanks, sewage, urban rainfall, groundwater infiltrated into sewage, industrial site drainage, etc.). In order to protect the environment and the human health, treating wastewater is essential. As reported in Metcalf and Eddy (2003) "the ultimate goal of wastewater engineering is the protection of public health in a manner commensurate with environmental, economic, social and political concerns".

The activated sludge process is the most used process to treat wastewater. It is based on aerobic degradation of wastewater components by using a suspended growth of microorganisms. The process is highly efficient and easily to manage but requires an aeration tank to feed oxygen to the biological colony of microorganisms. Under the energy and sustainability point of view, the activated sludge process has a big disadvantage: about 60÷70% of the total energy consumption of a whole municipal wastewater treatment plant is used for aeration (Jiang and Stenstrom, 2012).

Under these circumstances, the target of wastewater treatment industries is about designing an aeration process to transfer the highest amount of oxygen from gas phase to the liquid phase with the highest efficiency and the lowest costs. Taking into account these aspects it is important to comprehend the properties of the liquid in which the oxygen mass transfer process occurs. As a result, an accurate knowledge of the sludge characteristics and behavior is fundamental.

In this thesis, we investigated the effect of the sludge viscosity on the characteristics of the aeration process. This situation is highly effective in MBRs where the high MLSS concentration causes a significant increase of sludge viscosity and widely effects the aeration process.

In order to simulate the behavior of activated sludge, different aqueous solution of Colloidal Silica (CS) and Xanthan Gum (XG) were prepared and their rheological behavior was determined by using a rotational rheometer.

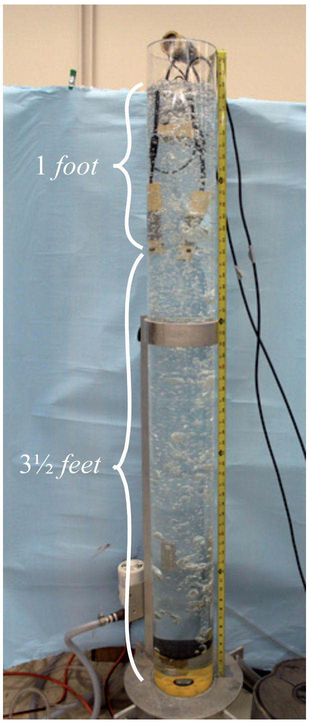


Figure 1: Tank setup

By using a laboratory scale tank (Fig. 1), the oxygen transfer efficiency parameters were calculated through the Clean Water Test procedure by using the US Standard (ASCE, 2006). Values of the volumetric mass transfer coefficient $K_L a_{20}$, Standard Oxygen Transfer Rate (SOTR) and Standard Oxygen Transfer Efficiency (SOTE), obtained at various airflow rates, were correlated with liquid's viscosity.

We observed (Fig. 2) that the Xanthan Gum solutions perfectly simulate the behavior of MBRs activated sludge. The rheograms regarding the Xanthan Gum (in color) are mostly equal to the rheograms of a MBRs activated sludge (in gray). In particular, we noticed that the behavior of 1 g/L solution of Xanthan Gum is completely comparable to the behavior of 16 g/L MLSS concentration of MBRs sludge.

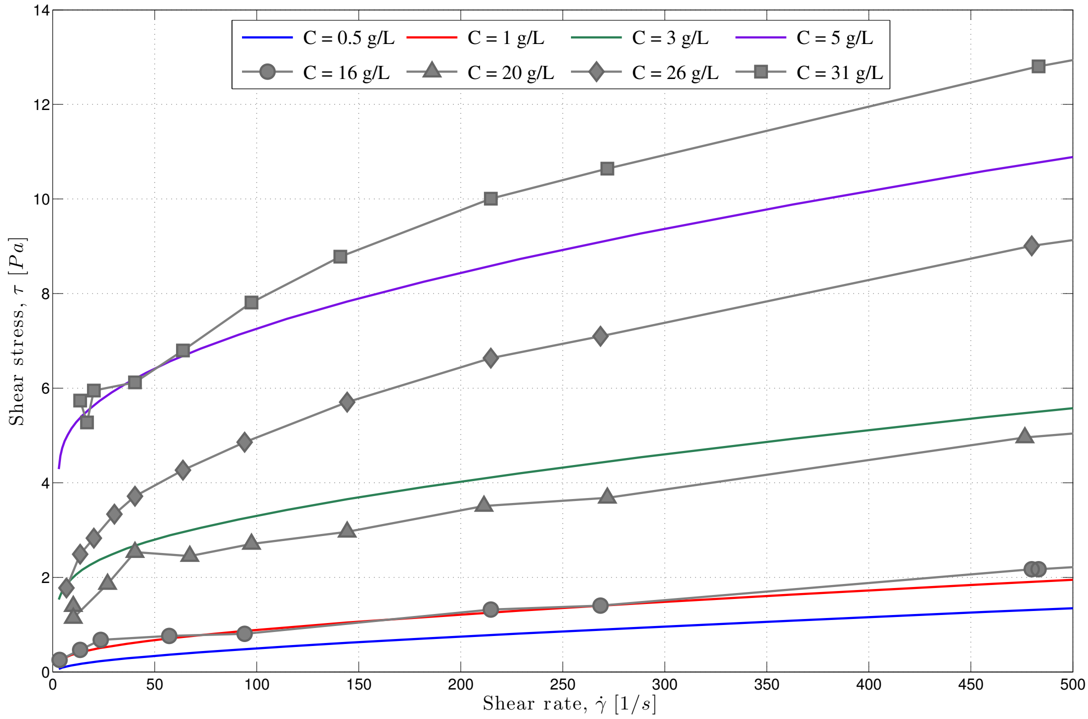


Figure 2: Rheograms of Xanthan Gum solutions vs. MBRs Activated Sludge

An overall of forty-seven Clean Water tests (Tab. 1) were conducted at three different Xanthan Gum concentrations (0 g/L – 1 g/L – 2.5 g/L) and at three different airflow rates (25 SCFH – 30 SCFH – 40 SCFH).

Table 1: Configurations adopted for the clean water tests

System	Aeration device	Fluid
(a)	Coarse bubble diffuser	Tap Water
(b)	7mm Nozzle	Tap Water
(c)	3mm Nozzle	Tap Water
(d)	3mm Nozzle	1 g/L aqueous solution of XG
(e)	3mm Nozzle	2.5 g/L aqueous solution of XG

We observed that the values of K_La_{20} and SOTR increase linearly as the airflow rate increases while the values of SOTE are constant or slightly decrease.

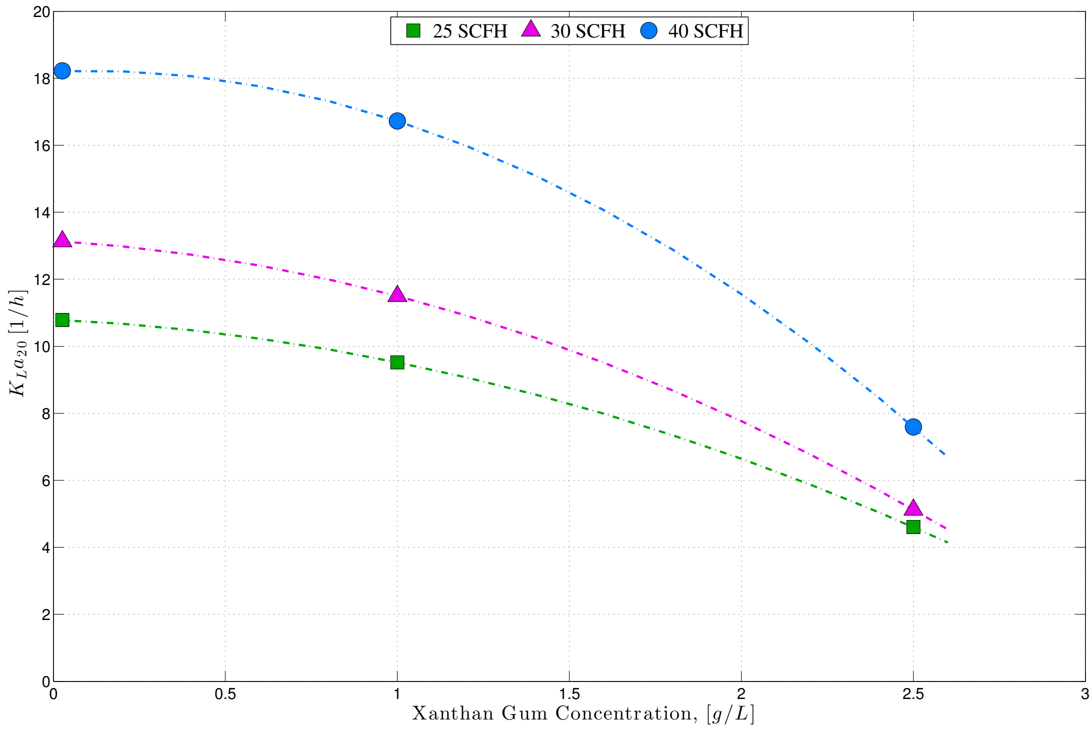


Figure 3: Evolution of the overall gas transfer coefficient as a function of the Xanthan Gum concentration (3mm nozzle)

For the 3mm nozzle, the values of $K_L a_{20}$, SOTR and SOTE at a specific airflow rate decrease as the Xanthan Gum concentration, or the liquid viscosity, increases. As result, the increasing of fluid's viscosity, negatively influences the oxygen mass transfer.

For any airflow, the $K_L a_{20}$ reduction (Fig. 3) becomes equal to an average of 11% when the Xanthan Gum concentration increases to 1 g/L and to 59% when the Gum content is 2.5 g/L. The reduction of $K_L a_{20}$ is due to the increase of the coalescence process. The liquid viscosity promotes the coalescence: bubbles combine in clusters and form large bubbles. Large bubbles have smaller interfacial area (a) and a high rising velocity that keep them in the liquid shorter, allowing less time for the oxygen to dissolve.

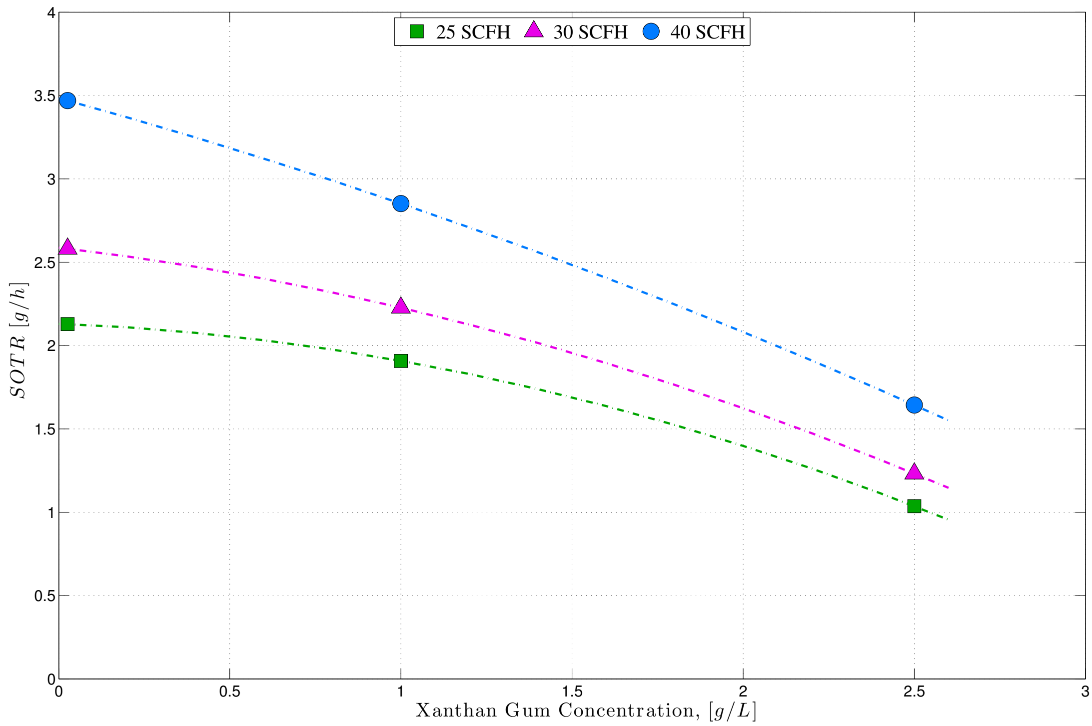


Figure 4: Evolution of the Standard Oxygen Transfer Rate as a function of the Xanthan Gum concentration (3mm nozzle)

For each airflow, both the Standard Oxygen Transfer Rate (Fig. 4) and the Standard Oxygen Transfer Efficiency (Fig. 5) reduce to an average of 14% and 52% when the Xanthan Gum concentration is 1 g/L and 2.5 g/L, respectively.

The values of SOTE are quite the same for any airflow rate.

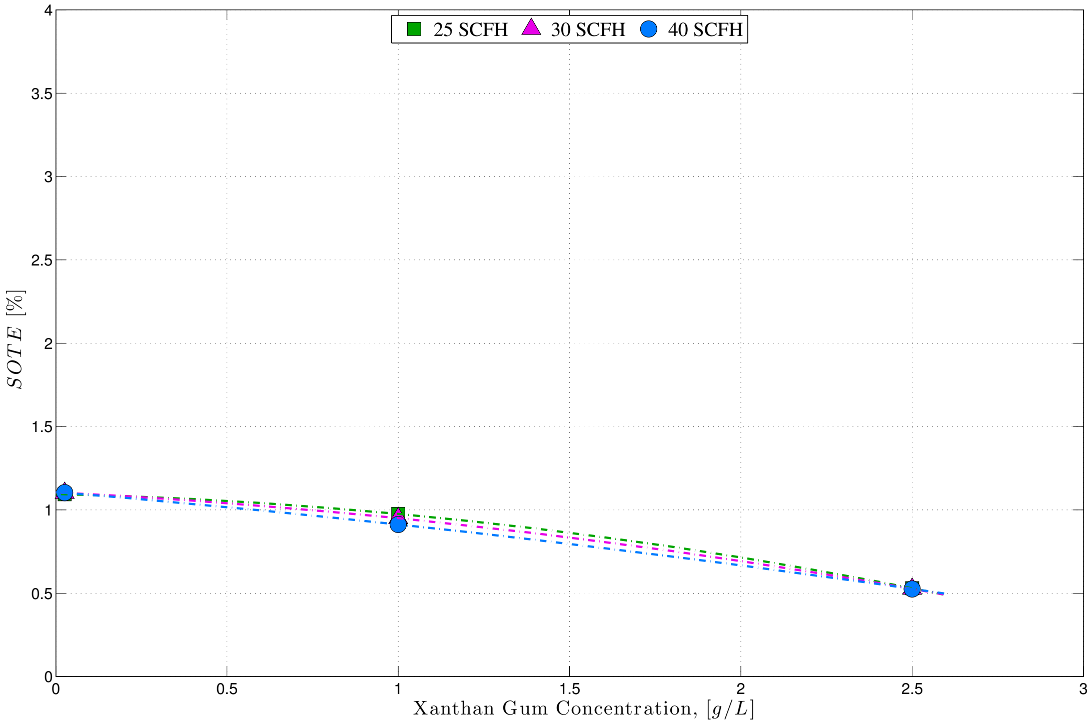


Figure 5: Evolution of the Standard Oxygen Transfer Efficiency as a function of the Xanthan Gum concentration (3mm nozzle)

The results we obtained are very important. We showed that when the Xanthan Gum concentration increases, the amount of oxygen transferred in water (SOTR) decreases. Nevertheless, at a specific concentration of Xanthan Gum and almost at the same efficiency, we can increase the oxygen transferred by increasing the airflow rare. Specifically, when the airflow is increased, the low decrease in efficiency is totally negligible compared to the big increase of oxygen transferred. As observed, an increase in airflow corresponds to an increase of the shear rate in the system. In other words, the shear rate promotes the oxygen transfer.

An explanation of this effect on real wastewater treatment plant can be found by analyzing the structure of the activated sludge. When the MLSS concentration increases, the filamentous organisms tend to flocculate in a large-scale network, creating flocs. During this process a large amount of water is incorporated into the particle structure. When the shear rate increases, the floc is disrupted and more water becomes available in the system, making the viscosity decreasing. As a result, the oxygen transfer process is improved.

In order to better understand the fluid dynamic of the system, we calculated the gas holdup fraction ε_G:

$$\varepsilon_G = \frac{V_G}{V_G + V_L} = \frac{H' - H}{H'} \qquad [\%] \tag{1}$$

where V_G and V_L are the gas and liquid volumes while H' and H are the height of aerated liquid and the clear liquid height.

When the liquid viscosity increases, at a specific airflow rate, the gas holdup fraction decreases (Fig. 6 and 7) because the total gas volume V_G in the system reduces. As observed before, an increment of the liquid viscosity promotes the coalescence phenomenon.

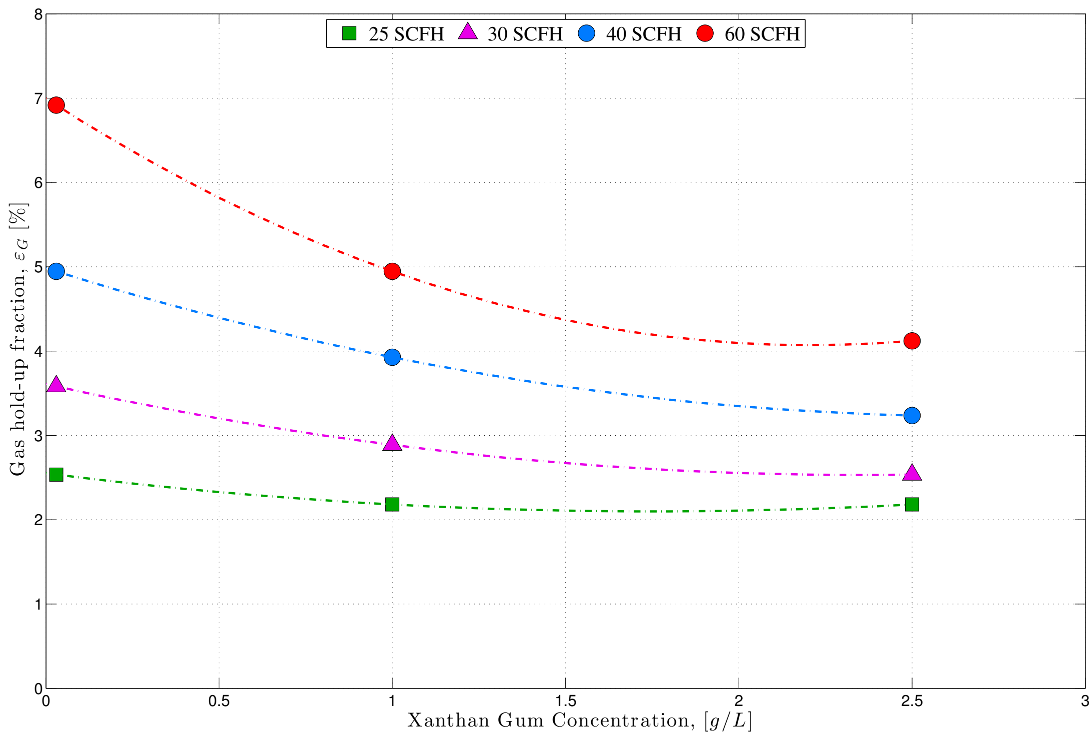
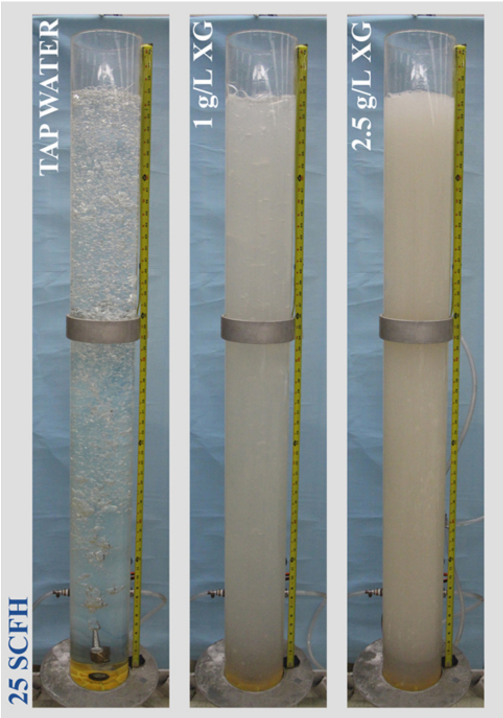
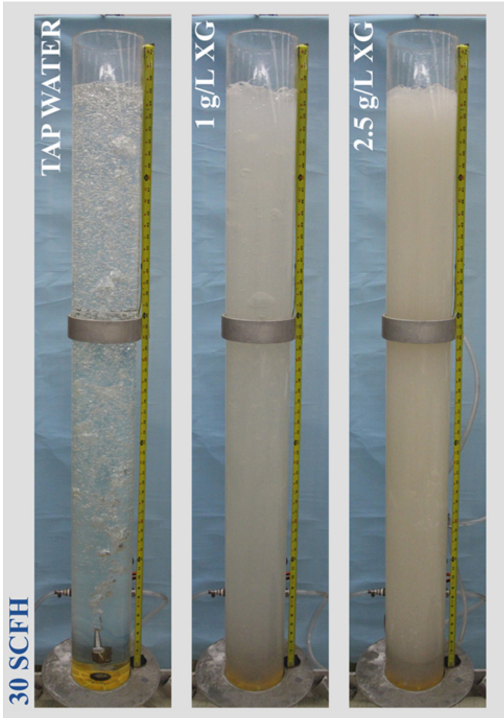


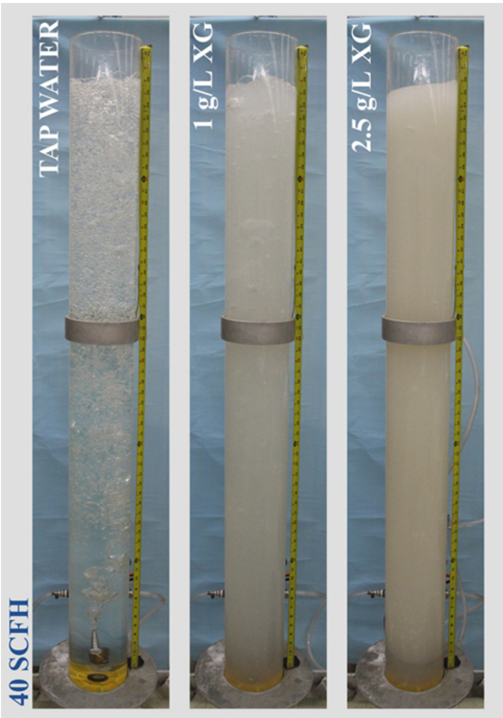
Figure 6: Gas holdup fraction for the 3mm nozzle as a function of the Xanthan Gum Concentration



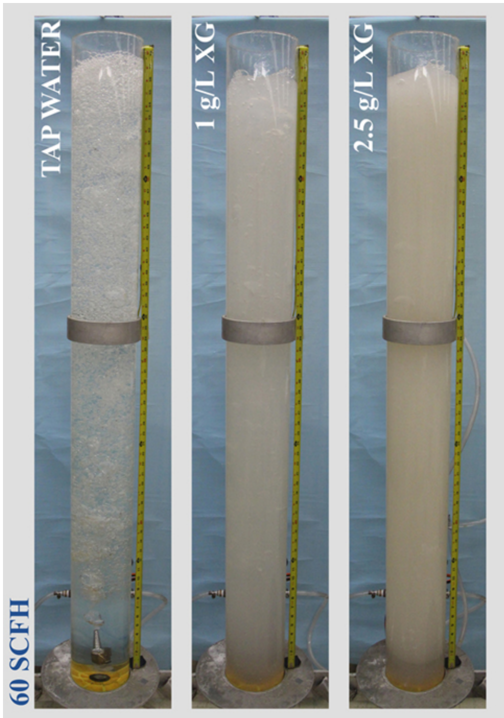
(a)



(b)



(c)



(d)

Figure 7: Gas holdup at specific airflow rate at different Xanthan Gum Concentration (a – 25 SCFH; b – 30 SCFH; c – 40 SCFH; d – 60 SCFH)

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