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# Intensification of Biodegradation with FLEXIPAK® Bioreactors in Industrial Pretreatment Plants

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***Abstract*— A pretreatment facility was established at the canning factory of EKO cPlc. in Nyíregyháza, Hungary between 2012 and 2013 for treating the highly concentrated industrial waste water generated during the processing of sweet corn. This is one of the largest canning factories in Hungary. The results and technologies used for the pretreatment of waste water generated during the main production seasons of the past 3 years are summarized, with special emphasis on CODCr and BOD5 parameters. The mass of industrial waste water was generally around 1200 m3/d or 50 m3/h generated evenly in the course of 3 shifts per day. The mechanical pretreatment phase consists of the following steps: fine screen, trommel screen, grit tank. The biological unit, developed by a Hungarian team, consists of multiphase, aerobic, submerged contact media units. The biological phase is distributed under the FLEXIPAK®-MIX brand name, while the submerged biofilm contact media unit under the TURBOPAK® brand name and both are manufactured in Hungary. These biofilm systems are collectively called System Gyulavári. The systems and models have been and still are being installed in many different structures. In the case of the EKO canning factory the concentration of raw waste water reached a maximum of as high as 13.000 mg/l CODCr and 6000-6500 mg/l BOD5 values at times. The mandatory treatment values specified for public sewer systems are: 1000 mg/l CODCr and 500 mg/l BOD5. The diameter of the FLEXIPAK®-MIX system, namely the circular steel structure, built in a ringed format, is 28 meters in total. A total of 680 m3 in-line TURBOPAK® contact-media had been built into these 2 rings marked as I. and II. forming a total of 102.000 m2 biofilm surface.**

**In the center of the structure a 9.0 m Ø DUALOX (System Gyulavári) ventilation unit has been installed in cells a, b, c and d joined in-line. Circular flow and supplementary O2 supply is ensured by 20 HP-Jet injector pumps which are suspended at 4 different locations resulting in 250-300 instances of contact with the biofilm for the waste water being treated on the surface of the fix contact units. Total time spent in the system is 2 days. The final complex polishing treatment is provided by the high pressure floating DAF equipment conditioned with chemicals. The results of 3 years of operation have proved the efficiency and cost effectiveness of the system. Based on organic pollutant content, the order of magnitude of the pretreatment system is 200.000 PE. From a global perspective, the system/structure is the first Hungarian patent (registered under 229.918 patent number, I. Gyulavári 2010) has ever built.**

***Index Terms*— Waste water pretreatment, FLEXIPAK®, TURBOPAK®, System Gyulavári, DUALOX process.**

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## I. INTRODUCTION

The treatment of the industrial waste water containing organic pollutants has been a serious problem to be dealt with worldwide, especially in the food industry [1-2]. Treatment efficiency is also a matter of great importance, as this is an important requirement at the point of direct reception as well. There had been several developments in this field of industrial waste water treatment during the past few years (Fig. 1.) [3-4]. The highly concentrated industrial waste water generated during the processing of corn was an especially difficult problem to tackle.

There are basically two processing technologies used in this field. One of the processers (e.g. FEVITA cPlc. Hungary) specializes is deep frozen goods, while another type of processing (e.g. EKO LLC Hungary) produces approximately 1.000.000 units of canned corn of 0.45 kg cans daily during season.

The authorities have ordered both companies to install industrial waste water pretreatment facilities before allowing them to connect to the public sewer system. In Hungary $COD_{Cr}$ content of waste water must be under 1000 mg/l before a permit is given to connect to the public sewer system. In factories and plants, where sweet corn is processed in industrial quantities, several different technologies have been tested using Pilot Plant equipment [5-6]. Certain research and development professionals saw the solution in using chemical pretreatment, but these attempts have not been proven successful [7]. The high starch, sugar and protein content did not respond well to the traditional AS live sludge, drop by drop, etc. methods using coagulating chemicals. An additional problem was that the relatively hot production temperature (40 ºC) of the industrial waste water generated during production caused the starch within the water to become gel like, which made the input of solute $O_2$ and turbulence for example impossible.

The anaerobic phases used for the creation of a biogas production facility did not result in a dependable solution due to the regular switching of products, the seasonal nature of the facility and high development and operational costs [8-9]. The specialized engineering firm of GYULAVÁRI CONSULTING Ltd. (Budapest) has designed a pretreatment facility back in 2001 which was installed at FEVITA LLC [10].

GYULAVÁRI CONSULTING Ltd. developed a FLEXIPAK® system using its own patented solution, which is an aerobic, submerged TURBOPAK® contact-media, producing the required threshold values without sludge concentration, using only the above mentioned biofilm biology. The structure was developed for treating Q = 1500

$m^3$/d waste water and are still used today during production season.

Based on this favorable track record another manufacturer mentioned earlier, namely the EKO Canning Factory commissioned GYULAVÁRI CONSULTING Research and Design Engineering Ltd. to design an industrial waste water treatment system for their sweet corn processing factory, which would operate as a pretreatment unit before connection to the public sewer system in a city.

## II. MATERIALS AND METHODS

Table 1. The load values for the task at EKO Ltd. were as follows

| | |
|---|---|
| Q = daily waste water load | 3000 $m^3$/d |
| Q max. = highest hourly value | 100 $m^3$/h |
| Quantity of waste water from corn | 1200 $m^3$/d |
| Average hourly value: | 50 $m^3$/h |
| Maximum periodic $COD_{Cr}$ contamination of waste water: | 13.000 mg/l $COD_{Cr}$ |
| Periodic waste water maximum $BOD_5$: | 6.500 mg/l $BOD_5$ |

Planned prephases for the EKO Project:

- Industrial waste water sewage pump
- Fine screen (1,00 mm, 100 $m^3$/h)
- Grit tank 100 $m^3$/h
- FLEXIPAK® (System Gyulavári) biological phase, aerobic, submerged contact-media with TURBOPAK® media

Total volume of reactor: 2644 $m^3$

Shape: 3 piece circular collection tank

Table 2. The most important dimensions of the reactor

| | |
|---|---|
| Total diameter, external diameter of the reactor: | 28,0 m Ø |
| External ring **I**: | 28,0 m Ø |
| Central external ring **II**: | 13,0 m Ø |
| Inside circular piece **III**: | 9,0 m Ø |

Structural makeup and installation of the biological phase: made out of prefabricated steel panels with an enameled surface and prefabricated bolted joints.

Manufactured and installed by: GLS International GmbH (Austria)

Table 3. The most important dimensions of the biofilm and aeration unit

| | | |
|---|---|---|
| Built-in TURBOPAK® fix contact-media Built-in specific biofilm/$m^2$ | 680 $m^3$ | In 1 $m^3$ = 150 $m^2$ |
| Total amount of biofilm | 102.000 $m^2$ | 680 $m^3$ x 150 $m^2/m^3$ |
| Built-in aeration units: | 1000 pieces | of Supratec (Germany) |
| Amount of air: | 3000 $m^3$ air/hour/piece | 4 compressors Kubicek (Czech Republic) |
| Aeration units for horizontal flow Alternative, internal recirculation This is not a sludge recirculation! | 20 units V = 3 kW/pc 4 units 1440 $m^3$/h, 400l/s | Herborner GmbH Linn - L3 0,5 typ. |

Flow and connection process after mechanical pretreatment:

- There is a circular flow primarily within ring **I**.
- Circular flow continues in ring **II** connected to the others in-line.
- Finally, within ring **III**, that is the circular basin divided into 4 equal parts, there are 4 basin units, which are where the treatment continues using floating Linn ventilation units, one for each part, making a total of 4 and Tsurumi (Japanese) ventilation pumps working intermittently at the bottom of each section within the reactor.

Raw water inlet is a point source load which arrives at the biological phase **I**.

There is a point source load at point A/1.

The water is transferred within rings I and II into sections A-B and B-C. Flowchart.

Water is transferred through a 0.6m x 1.0m "window" on the wall of the basin ring through a cascading connection.

Pretreated waste water is let out of the system through cell d of the center section (**III**) through a spillover trough and/or, depending on current operational conditions, by continual pumping into the high pressure DAF floating, polishing phase. Final control and point sampling of the pretreatment of industrial waste water is carried out at point B of the water flow out. The main parameters tested are the $COD_{Cr}$, $BOD_5$ and SS values.

## III. RESULTS

The technological process of the fully built FLEXIPAK® waste water treatment system is on fig. 1. Technological waste water generated during industrial production is collected at the central sewage pump with the help of a separate accumulation system, where 2 pumps feed the accumulated waste water onto the mechanical pretreatment unit. The sewage pump operates automatically and is started by a floater.

Capacity of the sewage pump: 2 x 70 l/sec/ unit

Mechanical pretreatment unit: 2 trommel screen units. Manufacturer: TE Ing. GmbH (Germany). Grade: 1.0 mm sieve density (914 mm). Model of the 2 trommel screens: TE-9025

Capacity per unit: 247 $m^3$/h l/sec. The waste water is transferred from the 2 trommel screens into the grit tank through a gravitational Na pipe 300 mm Ø in diameter.

The main structure of the grit tank is made out of premanufactured steel and is a gravitational type equipment with a capacity of 100 $m^3$/h.

Manufacturer: AKVI-Patent Co.Ltd. Hungary.

The separated sand is transferred from the equipment to the feed outlet with the help of a pulley hoist where it is collected into containers and hauled off to a waste deposit.

The waste water being treated moves on gravitationally from the grit tank to the outer, 28 m Ø FLEXIPAK® ring bioreactor, marked I. Continuous flow is maintained at section I of this structure within the ring with the help of HP-Jet ventilation pumps suspended from the technological steel bridge also used as a walkway.

Besides the continuous operation of these HP-Jet pumps the water is constantly being mixed and homogenized at the point of inlet, the water being mixed with the substance, or water, flowing into the ring. The HP-Jet pumps have air suction pipes obtaining air from above the operational water level and getting oxygen into the water. The HP-Jet pumps ensure horizontal flow within each ring of the circular reactor.
The reactor, 28 meters in diameter, has 4 steel bridges at 90º angles with 4 + 1 HP-Jet pumps suspended in section **I**. Width of the bridges: 1.2 meters, which also provide uninterrupted operation, periodic inspection of machinery and may be drawn up for inspection of replacement if and when needed.
The multi-cell TURBOPAK® contact units have been placed in the polygon after the circular area of rings I and II, which have prefabricated stainless steel frames.
Size of contact units: 1,2 m x 1,6 m x 2,4 m (height). The TURBOPAK® contact units weigh approximately 30 kilograms each and are quite easily installed using cranes, since the steel frames are equipped with hooks for transportation, so lifting them into their suspended positions was easily accomplished. These hooks make the replacement of contact units very simple as well. Width of contact walls: 1.2 meters, and their height is: 2.4 meters.
Operational water level is 4.0 meters within the reactor and the TURBOPAK® contact walls form a circular ring. The bottom structure of the reactor is monolith and is made out of a 0.4 m thick reinforced iron sheet.
The plastic air distribution pipes, 500 mm in diameter, were mounted on top of this. Air is supplied from the engine-house, which is a separate building next to the FLEXIPAK® reactor. The aeration units are 160 mm in diameter and are 1100 mm long. Model: OXYFLEX® MF 1100, manufacturer: SUPRATEC GmbH, a German company.
The aeration units are located directly at the bottom section.
Dual aeration can be ensured for the plastic TURBOPAK® contact units and on the biofilm surface forming on its channels:
a/ one is the air coming from the aeration compressor.
b/ and an ample supply from the oxygen coming from the 20 suspended HP-Jet pumps.

The desired amount of solute oxygen concentration is 2-3 mg/l $O_2$. This value was maintained at all times. The process can be regulated by the central aeration equipment by determining the number of machines and also through the solute oxygen level indicators.
There is no concentrated live sludge within the FLEXIPAK® reactor, only biofilm!
Biodegradation is ensured by the biofilm via the TURBOPAK® contact units.
The substance within the FLEXIPAK® system results in a sludge concentration of 0.2 -0.5 kg/m$^3$.Within traditional systems the usual sludge concentration is measured at 5-6 kg/m$^3$.
Industrial FLEXIPAK® installations do not have clarifiers or sludge circulation, as it is not necessary in the case of FLEXIPAK® systems.

From ring **I** the waste water being treated flows into ring **II** aided by gravitation alone through the 0.6 m x 1.0 m vertical opening or window at the bottom.
The structure of ring **II** is identical with ring **I**. The clean water recirculation pumps start from ring **II** built with L3, NA200 pressure lines and led into ring **I.** This solution provides the possibility of periodic intervention.

The 9.0 m Ø inner section, marked III, is divided into 4 cells. Flow from ring II into cell a/ is ensured by a vertical "window" or opening in the partition wall aided by gravitation alone, and so the compound arrives into cell a/.

The four cells are placed in-line in a cascading structure. Each cell has a Tsurumi Model 32TRN21.5 ventilation pump installed towards its bottom section.
Within the upper part of the reactor other ventilation equipment are installed with Linn floaters. Model: L3-0,5, and a capacity of 0.75 kW/unit.
This combination provides an additional and combined effect. The Tsurumi pumps also work as ventilation units. The rough, bubbly product of this phase is "pulverized" by the Linn floaters, ventilators working on the surface and the resulting substance, with its small bubbles increasing the oxygen intake, which is very beneficial for the cleaning and final polishing phases. The aerobic state ensured in different ways ascertains a stable, odorless operation at all times.
The spillover trough system, responsible for directing the treated water out of the system, is installed in cell d/, being the last cell, of section III, which ensures outflow by allowing spillover water to leave.
Another pump is located in the same cell, ensuring periodic or constant pumping, feeding of the water into the DAF (Dissolved Aerobic Flotation) machine which is responsible for polishing. After successful and intensive degradation the water is concentrated in cells characteristic of the water being treated and which cannot be treated with traditional sedimentation processes. The final treatment and result is provided by the polishing phase which is a high pressure flotational equipment conditioned with extra chemicals.
Chemical conditioning is done through polyelectrolytes and coagulating chemicals. The DAF equipment is manufactured by KORAX Ltd. and is a Hungarian product, ensuring cost effective, efficient and successful operation, applying divers modern solutions. Q capacity: 50 m$^3$/h, 13,88 l/sec
Chemicals within the pipe are mixed in with a static mixer. Pressure is increased with the help of special pumps (Typ. EDUR) manufactured in Germany.
A solution using a louver has been installed within the phase breaker space.
The last phase contains a sludge thickener to eliminate water. The outflow of treated water provides the final result which is kept up at all times. (Point AB is the point of measurement and sampling.)
This is transported to the City's Central Waste Water Treatment Plant where it is used in sludge digestion and "biogas" reactor and other digestion facilities to increase the quantity and quality of the plants' production.

Table 4. Regular and continuous regulatory sampling and laboratory analysis showed the following results

| Period | COD mg/l effluent concentration | COD limit mg/l | effluent m$^3$ | pollution kg | over the liminal value kg |
|---|---|---|---|---|---|
| 01.01-03.25 | - | 1000 | 3868 | - | - |
| 03.26-06.08 | 112 | 1000 | 7722 | 865 | - |
| 06.09-06.22 | 167 | 1000 | 9623 | 1607 | - |
| 06.23-07.06 | 567 | 1000 | 14306 | 8112 | - |
| 07.07-07.20 | 77 | 1000 | 10531 | 1275 | - |
| 07.21-08.03 | 65 | 1000 | 12903 | 839 | - |
| 08.04-08.24 | 66 | 1000 | 26308 | 1736 | - |
| 08.25-08.31 | 342 | 1000 | 10854 | 3712 | - |
| 09.01-09.14 | 391 | 1000 | 16146 | 6313 | - |
| 09.15-09.28 | 394 | 1000 | 13881 | 5469 | - |
| 09.29-10.12 | 30 | 1000 | 9481 | 284 | - |
| 10.13-11.16 | 241 | 1000 | 7969 | 1921 | - |
| 11.17-12.31 | - | 1000 | 5122 | - | - |
| **total** | | | **144.814** | **32133** | **-** |

From these operational figures we can obtain the previously unknown principles which govern the basics and sizing of this unique structure.
It is a basic necessity to build a Pilot Plant before going on with the implementation of the task at hand, to help establish certain basic conditions, such as:

- Whether it is biologically possible to degrade the waste, especially in the case of those originated by industrial processes,
- Percentage and concentration of industrial canning factory pollutants found in the waste water,
- Other traceable or determinable parameters, etc.
- Establishing expected loads and concentrations in the respective industry, such as in the case of canning factories,
- It is a requirement to know the processing time of certain raw materials, material types, such as seasonal products, their quantities, or the annual change of these values, if any, etc.

The requirements and changes listed can be easily satisfied with the FLEXIPAK®-MIX system, as its aerobic nature ensures that all aerobic processes and the adaptation of related microorganisms are maintained regardless of the current load or prevalent parameters.
Based on the number of unique cycles within the FLEXIPAK®-MIX reactor we can easily establish the approximate number of contacts with the biofilm.

*ro (radius) = ca. 12,0 m ( 12,0 m average cycle)*
*2 x 12 = 24 x 3,14(2 rπ) = 75,36= 75,36 m : 0,3 m/sec = 240 sec*
*Time of one circulation = ϕ = 75,36 m : 0,3 m/sec = 251,2 sec that is 4,18 min/ 1 circulation*
*For the case at hand total T = 2 d = 48 hours*
*Total circulations, cycles, which means the circulation of all the water*
*48 h x 60 = 2880 minute = 688,99 cycles/2 days*
*4,18 minutes*
*In 1 hour = 60 : 4,18 = 14,35 circulation cycles*
*In 1 day 1440 x 60 = 344,49 circulation cycles*

Depending on the type of load this value can be reduced.
This value can be called a Contacting Index, which is a relative number.
During the cycle the load changes continually, including the number, specimen and population of the microorganisms forming the biofilm.
The load range for the surface of the contact walls by the ring can be illustrated or explained with a clothoid spiral. Depending on the number of contacts this process is repeated n times.
Biodegrading processes can be regulated in certain cases. The regulation is achieved with horizontal flow, increased speed, by regulating the RPM of the HP-Jet ventilation pumps for example or by operating them by phases.
We should note here that unlimited underload is also possible.
The makeup of microorganisms cultivates depending on the relevant load.
In ring **II** the contacting index value continues to increase, relative to the shorter path.
In Ring **III**, which is divided into 4 cells, polishing and disintegration continues and $O_2$ content becomes richer.
There is a cascading flow in these sections where turbulence and oxygen concentration, as well as oxygen intake, can be efficiently regulated.
This is made possible with the help of the so called DUALOX® (System Gyulavári) ventilation system.

## IV. CONSLUSIONS

The implementation of the modern FLEXIPAK®-MIX system with TURBOPAK® (System Gyulavári, 2010) contact units for treating waste water generated by corn processing industries was based on the Hungarian 229918 patent. The system satisfies official requirements set for waste water treatment and operates successfully at the EKO Canning Factory in Hungary.

- These operational experiences show that biodegradation of organic pollutants is possible and the method can be useful in the complex, biological treatment of waste water in over 30 different industries having to deal with organic pollutants.

- The adaptation of microorganisms in technologies using biofilm and contact units has been well established even for varying load impacts.
- The in-line, cascading arrangement of spaces has a beneficial effect in FLEXIPAK®-MIX type compact equipment. The circular flow technology is a combination ventilation system with high range, aerobic $O_2$ intake into the biofilm, at lower surplus sludge levels, compensating for the varying load ranges.
- The adaptability of microorganisms on the biofilm to different ranges of load is significant.
- The PVC carrier used for TURBOPAK® media complies with relevant regulations.
- The applied UV protection is beneficial, adhesion of the microorganisms to the surface is satisfactory and acceptable.
- The FLEXIPAK®-MIX structure is circular, with a ringed structure and requires relatively less space and has a smaller footprint.
- The aerobic nature of the FLEXIPAK®-MIX system provides a workable solution with a sufficient regulation of $O_2$.
- In case of biological implementations using contact units and biofilm under climatic conditions bellow 15ºC, nitrification is more intense than in the case of traditional AS (activated sludge) systems.

As opposed to the traditional AS systems, there is no need to add live sludge to the mix when a FLEXIPAK® is installed.
The system must be filled with "clean water" of adequate quality upon startup. Regular city water coming from the public water network, water from wells, streams, springs, rivers, lakes or other stagnant water sources are in most cases satisfactory for this purpose.

The FLEXIPAK® system can be started up and loaded with as low quantities as 0.5-10 $m^3$/d, therefore there are no lower limits to its capacity relative to its volume.

- The initial feed includes a preliminary ventilation phase, resulting in a certain (0.5-1.5 mg/l) oxygen concentration within a given volume, after which raw waste water load can gradually begin, starting the formation of biofilm, depending on current climate conditions.
- The final state of the biofilm forms in relation to the given temperature, being different in each case and in each season. In case of the presented example at the EKO factory, the startup period was 8-10 days.

During periods when the system worked way under its normal capacity cleaning efficiency was higher. When occasionally the foam forming on the surface shows harmful or disadvantageous values, Antispumin may be administered to check the process, but this has no effect on normal operations.

- In case a disadvantageous change occurs in pH value and it drops below pH 6, Sodium hydroxide (NaOH) may be fed into the system to balance the pH value.
- Feeding industrial, technological "hot water" into the system, over 40ºC for example, is not beneficial.
- Over 30ºC water temperature the entering of $O_2$, soluble oxygen, into the medium, the biofilm, is disadvantageous and limiting and therefore not cost effective.

$O_2$, pH and SS parameters need constant monitoring. The quantity of surplus sludge is approximately 30-40 % compared to the traditional AS systems.

- It is advisable to process the remaining organic matter - biomass waste - within the biogas sector.
- In case of technical timeouts, such as a power cut, the aerobic system transforms into an anoxic, then into an anaerobe state, depending on timing. When power is restored, the aerobic state can be restored within a short time, approximately 2-3 hours, without any elaborate intervention.

This means increased operational safety.

In case of changes in the load, such as the concentration or type of waste water being added, the microorganisms forming the biofilm automatically balance their own type and population indigenously and compensate for the changes. Their buffering capacity is quite large. In cases like these the variation in cleaning efficiency is minimal, the system is not upset.
The operational time and changes in RPM of the HP-Jet pumps or ventilators, responsible for ensuring horizontal flow within the system, can also be regulated. Using this regulation method the number of revolutions within the ring and the number of contacts within a given section can be modified.
The adhesion of the TURBOPAK® immobile biofilm onto the surface has been proven satisfactory. The changes in the thickness of biofilm over time, depending on load, were resolved automatically. No clogging processes were detected and there was no need to institute flushing cycles. The grade of the separation screens of mechanical phase separation equipment connected to the system was proven adequate.
The hydraulic sizing of the piping, built for the periodic and complete drainage of the system, should be reviewed. It seems more beneficial to have pipes with a larger diameter to decrease the time needed for draining. During peak seasons or during times of maximum hourly values, the change in load on the biofilm does not affect cleaning efficiency.
The periodic needs for added $O_2$, as well as the prevailing need for air, and changes in feed, are all resolved through the automatic system. It uses an automatic $O^2$ measuring and control probe system - electrodes - for regulation, so the current demands for air within the system are ensured by the RPM regulating features of the built-in air ventilation equipment. The system operates in an open environment (without an overhead roof), so climatic factors and effects have a direct influence on it.
An increase in operational temperatures was observed within the reactor, especially during the summer months of June, July, and August. There was no significant decrease in efficiency as a result and the possibility of cooling by adding industrial cold water of 20-25ºC was available, although this a costly solution.

The stability of the main air distribution pipe should be periodically inspected. The micro sludge particles floating within the FLEXIPAK® reactor cannot be settled gravitational, therefore traditional settling methods cannot be applied. The installation of the modern and cost effective DAF flotation machine was deemed necessary, thus further increasing the total cleaning effect of the system.

The size and technical equipment of the current system may be expanded if the need should arise. Added load, meaning approximately 30-50 % increase in capacity and a flexible intensification, may be accommodated by installing additional floating, mobile contact units, which would provide a larger contact surface and biofilm surface for the biodegradation processes. Based on the processes, positive characteristics, efficiency, cost effectiveness and stability of the FLEXIPAK® system, we can establish that it is definitely a recommended solution for the treatment of organic industrial waste water and is also a legitimate solution for communal, biological waste water treatment plants, both for new systems and in cases where intensification is needed as well. The combined use of double biofilm ensures that air is utilized beneficially, which can be demonstrated by the kg/$O_2$/h value.

Using the FLEXIPAK® system ensures sustainable development in communal and industrial waste water treatment.

Figure FLEXIPAK® MIX Bioreactor (EKO)

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