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Original Research Paper

Significance of Physical Parameters of Coagulation-Flocculation in Water Treatment with *Moringa Oleifera*

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ABSTRACT

Rapid and slow mixing of coagulant with the water to be treated are the steps in the process of coagulation-flocculation. There are several factors, both physical and chemical, which influence the process of coagulation-flocculation. Design criteria suggest that the principal parameters of rapid mix and slow mix for the purpose of design and functional evaluation are velocity gradient and time of mixing. The shape of the mixing unit and the baffles into it also affect the process of coagulation-flocculation. Also the turbidity and nature of turbidity have influence on effective turbidity removal. The experiments were performed to study the significance of type of turbidity, shape of mixing unit and the baffles into it, velocity gradient and time of mixing on turbidity removal. The herbal coagulant *Moringa oleifera* and its various forms were used in the study. The experiments were performed using two types of clay turbidities with 50 NTU, 150 NTU and 450 NTU turbidity value. The circular baffled jar was found to be most efficient for turbidity removal. The rapid mix velocity gradient of 720 s^{-1} and slow mix velocity gradient of 90 s^{-1} gave the maximum turbidity removal efficiency.

INTRODUCTION

Coagulation plays one of the important roles in water treatment. One of the common coagulants is alum, but the main problems associated with it are its low availability and high cost involved in manufacturing alum (Litherland 1995). However, recent studies have pointed out several serious drawbacks of using aluminium salts, such as Alzheimer's disease and similar health related problems associated with residual aluminium in treated waters (Crapper et al. 1973, Miller et al. 1984), besides production of large sludge volumes. There is also the problem of reaction of alum with natural alkalinity present in the water leading to a reduction of pH, and low efficiency in coagulation of cold waters. A significant economic factor is that many developing countries can hardly afford the high costs of imported chemicals for water treatment (Ndabigengesere 1995). Ferric salts and synthetic polymers have also been used as coagulant but with limited success, because of same disadvantages as in the case of aluminium salts.

Natural coagulants of vegetable and mineral origin have been used in water and wastewater treatment before the advent of synthetic chemicals like aluminium and ferric salts, but they have not been able to compete effectively because of the fact that a scientific understanding of their effectiveness and mechanism of action was lacking. Thus, use of natural coagulants has been discouraged without any scientific evaluation. They have succumbed progressively under modernization and survived only in remote areas of some developing countries (Jahn 1988). Recently, however, there has been resurgence of interest in natural coagulants for water treatment in developing countries.

Moringa oleifera has been one of the most widely used natural coagulants in many developing countries (Litherland 1995). Studies have reported that *Moringa oleifera* has good coagulation property (Jahn 1988, Olsen 1987, Muyibi & Evison 1995, Nkhata 2001).

Except in traditional use and in some laboratory or pilot studies, no large exploitation of *M. oleifera* in water treatment has been reported so far. This rejection may be explained by the presentation of *Moringa* as a low technology appropriate only to developing countries (Jahn 1988). One way to improve acceptance of *Moringa* as a coagulant all over the world is to show clearly its advantages over conventional coagulants and apply modern technology to supply it to water treatment industry at cheaper cost.

The addition of mineral salts or organic compounds causes the agglomeration of unsettleable particles (Alaert 1981). In most water treatment plants, the minimal coagulant concentration and the residual turbidity of the water are determined by the Jar-Test technique (Dempsey 1984). Kawamura (1976) has shown the importance of the nature of clay suspension on residual turbidity and coagulant levels at optimum flocculation.

Significance of velocity gradient (G) value: The significance of the G value for coagulation-flocculation processes is not univocal. Klute & Hahn (1974) found that the local energy dissipation of the stirrer plays an important role in the kinetics of flocculation and in the removal efficiency of suspended solids. According to Letterman et al. (1973) improvement in turbidity removal can be obtained by varying factors like rapid mix RPM, rapid mix time and concentration of coagulant. Experiments were carried out in order to investigate the influence of different G values and different jar configurations.

In all the investigations carried out so far, parameters used in conventional jar test have been used to evaluate the coagulation efficiency of *M. oleifera* in the treatment of surface waters and synthetic waters. In all such studies the physical parameters like slow mixing velocity gradient and time, rapid mixing velocity gradient and time were fixed according to standard jar test values for alum coagulation. The only parameter varied in most of the cases was doses of *M. oleifera.* Furthermore, studies into the interaction between physical parameters affecting coagulation like slow mix, rapid mix rates and time are not documented.

The purpose of this study was to investigate the turbidity removal efficiency in square tanks and to compare this with cylindrical baffled and non-baffled tanks. In this study laboratory investigation was carried out to determine the multiple effects of physical parameters like initial particulate concentration (turbidity) and type of turbidity, jar configuration and slow mixing and rapid mixing velocity gradient, on coagulation of turbid water with *Moringa oleifera*. These parameters were varied and other parameters were kept constant and optimization was carried out for optimum values of doses of *M. oleifera* and other parameters.

MATERIALS AND METHODS

Seed analysis: Various tests were performed on *Moringa oleifera* in its various forms, the principle objective being the determination of its general composition and its potential use as natural coagulant in water treatment. Carbohydrates, protein and fat content were determined using the methods mentioned in Table 1 along with the results of the seed analysis.

The jars: The circular and square shape jars of one litre capacity with and without baffles were used. These were fabricated in perspex material. The tap was provided at the top to collect the supernatant for determination of residual turbidity. Description of jars is given in Table 2.

The turbid water samples: The natural turbidity of raw water varies from 10 to 500 NTU for maximum period. So the experiments were performed on low, medium and high turbid water samples of 50, 150 and 450 NTU turbidity values respectively. The kaolin and bentonite clay were used to prepare the turbid water samples. Five grammes (g) of kaolin/bentonite clay was mixed into 500 mL distilled water. Mixed clay sample was kept for soaking for 24 hrs. Suspension was then stirred in the rapid stirrer so as to achieve uniform and homogeneous turbidity sample. Resulting suspension was found to be colloidal and used as stock solution for preparation of turbid water samples. The stock sample was diluted by tap water to desired turbidity.

Jar test apparatus: Jar test apparatus is generally used for determining optimum dosage of coagulant in coagulation-flocculation treatment. Apparatus is fitted with 6 rotator blades, each having an area of 17 cm^2. This apparatus is provided with the speed control arrangements between 20 RPM to 200 RPM.

Preparation of seed extracts: The experiments were performed using various forms of *M. oleifera* extracts. The extracts of shelled seeds, deoiled seeds and protein powder were used in this study. Tree dried *M. oleifera* seeds were procured from trees of local area. Good quality seeds were then picked up. These seeds were used to prepare the extracts. The shelled seeds were crushed in a blender to fine powder. Then 5 g seed powder was mixed with 200 mL distilled water for 2 minutes and kept for further 2 minutes. Again, the mixture was stirred for 1 min and filtered through muslin cloth. Filtrate was diluted by distilled water to make it up to 500 mL. Resulting stock solution was having approximate concentration of 10000 mg/L (1%). Fresh stock solutions were prepared everyday for the one-day's experimental run.

To prepare the deoiled powder and its extract, the shelled dry *M. oleifera* seeds were crushed using kitchen blender. The 95% organic solvent (ethanol) in the ratio of 1:10 (1 g of seed powder and 10 mL of ethanol) was added into the powder. The suspension was stirred for 10 minutes and centrifuged to remove oil and ethanol mixture. Remaining powder was kept for drying. This deoiled powder was used to prepare the extract.

To extract protein from the seed powder following two steps were carried out:

Extraction of polymer from seed: The extraction of coagulation active component from *M. Oleifera* seeds using salt solution was found to be more efficient than the conventional method of using water (Okuda 2001). The coagulation capacity of *M. oleifera* coagulant extracted with 1 M solution NaCl solution was 7.4 times higher than extracted using water (Okuda 2001). The deoiled powder was weighed (50g) and dispersed in 1 M sodium chloride solution. Extract was filtered by Whatman filter paper No. 44 and collected as brown coloured sodium chloride extract. This extract was further heated till white precipitate should not form at the bottom.

Table 1: Results of Seed analysis.

Sr. No.	Sample Name	Parameters	Results	Units	Test Methods
1	*Moringa oleifera* seeds	Protein	36.90	%	AOAC 920.152
2		Fat	37.25	%	Ranganna
3		Carbohydrates	16.38	%	IS: 1656-1997
4		Crude Fiber	12.85	%	SP-18 (P-IX) 1984
5		Moisture	6.41	%	Ranganna
6		Ash	3.06	%	AOAC 940.26

Table 2: Types of jars used in the study.

Sr.No.	Type of jar	No. of jars	Dimensions (Internal)
1.	Circular Non-Baffled (CNB)	6	10 cm (dia) × 14 cm (H)
2.	Circular Baffled (CB)	3	10 cm (dia) × 14 cm (H) With 4 baffles (one at each quadrant point) of 1.1 cm × 0.2 cm all along the height
3.	Square Non-baffled (SNB)	3	9.1 cm (L) × 9.1 cm (B) ×14 cm (H)
4.	Square Baffled (SB)	3	9.1 cm (L) × 9.1 cm (B) ×14 cm (H) With 4 baffles (one on each side) of 1.1 cm × 0.2 cm all along the height

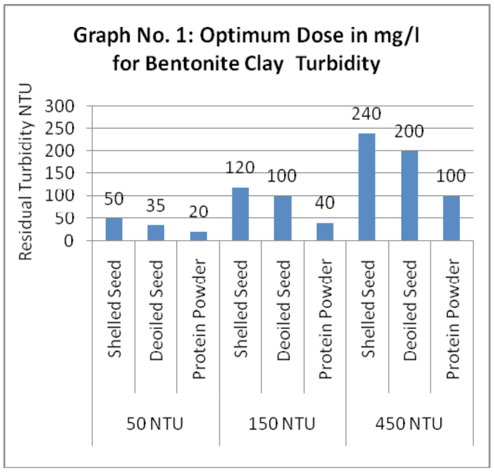
Table 3: Optimisation of dose.

Type of Turbidity	Type of Extract	Type of Jars	Initial Turbidity NTU	Optimum Dose mg/L	Average Residual Turbidity NTU
Bentonite Clay	Shelled Seed	CNB	50	50	5.0
		CNB	150	120	5.2
		CNB	450	240	5.2
	Deoiled Seed	CNB	50	35	5.2
		CNB	150	100	5.0
		CNB	450	200	5.6
	Protein Powder	CNB	50	20	7.8
		CNB	150	40	5.5
		CNB	450	100	6.7
Kaolin Clay	Shelled Seed	CNB	50	70	18.2
		CNB	150	130	22.0
		CNB	450	300	31.2
	Deoiled Seed	CNB	50	50	10.7
		CNB	150	100	25.2
		CNB	450	200	26.0
	Protein Powder	CNB	50	25	12.2
		CNB	150	47	10.7
		CNB	450	110	18.0

Purification of the polymer: Heated crude protein extract was further poured in to the dialysis tube (Himedia, Mumbai) and kept for 12 hrs in the beaker containing cold water. The beaker was kept in ice bath. After completion of dialysis, salts were removed out into the surrounding water solution and white protein remained inside the tube, which was removed out from the tube by rinsing with deionised water. This separated protein was homogenized with cold acetone for delipidization in a homogenizer. After delipidization this protein was dried at room temperature and used to prepare coagulant extract.

Experiment procedure: Turbid water sample of required turbidity was prepared by using tap water and stock solution of kaolin/bentonite clay. Then 500 mL sample was taken in all the required jars. Calculated dose of coagulant (1% concentration) was added to different jars filled with turbid water samples. Dosed jars were put on the Jar Test Apparatus. The samples were flash mixed and slow mixed at the predecided RPM and time duration. At the end of mixing the jars were taken out from the apparatus and were kept for 30 minutes for settling. At the end of the settling period, supernatant was taken to measure the residual turbidity. The residual turbidity was measured with the digital Nephelometer. The residual turbidity of the treated water sample was considered as the efficiency parameter.

Experimental runs: The scope of the work was to deal with



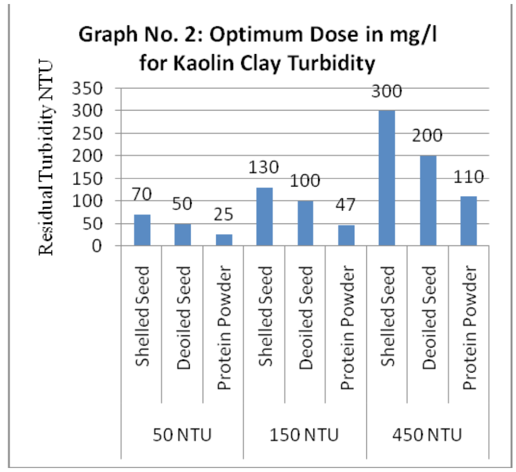


Fig. 1and 2 (Graphs): Optimisation of dose.

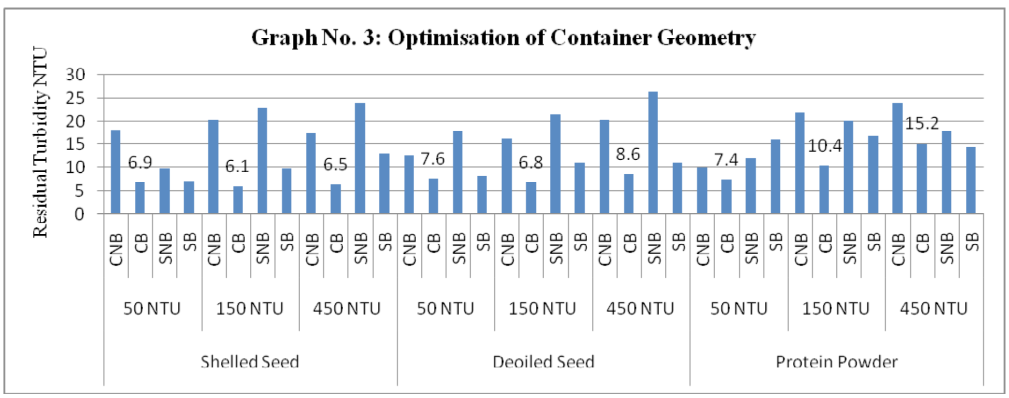


Fig. 3: Optimisation of container geometry.

the form of coagulant, type and nature of turbidity, jar configuration and the rapid mixing and slow mixing parameters which affect the effective floc formation and settlement characteristics of the turbid water. Entire work was divided into number of stages viz., optimum dose determination, optimization of jar configuration, optimization of rapid mixing and slow mixing parameters. In each stage one variable was changed while others were kept constant. After optimization of the first parameter i.e., dose, it was kept constant and other were varied.

In the Stage-1, optimum dose of coagulant required for the different initial turbidities like, 50 NTU, 150 NTU and 450 NTU was determined. The circular jars were used. The rapid mixing and slow mixing was done at 120 RPM and 30 RPM respectively. Dose of the coagulant, which was found to be optimum during the Stage-1, was used in all experiments of Stage-2, 3 and 4. Results were analysed by preparing the figures of dosages versus respective residual turbidity. Results are given in Table 3 and Figs. 1 and 2.

In Stage-2, the optimization of jar configuration was carried out. The circular baffled (CB), circular non-baffled (CNB), square baffled (SB) and square non-baffled (SNB) were used. In this stage the results were analysed by working out the variations in the residual turbidity with respect to jar configurations, which are reflected in Table 3 and Fig. 3.

Stage-3 dealt with the optimization of rapid mixing RPM (velocity gradient). The experiments were performed with 100, 120, 140 and 160 RPM with velocity gradients $545 s^{-1}$, $720 s^{-1}$, $910 s^{-1}$ and $1110 s^{-1}$. The optimized dose and the jar were used in this study. Results are given in Table 3 and Fig. 4.

Stage-4 dealt with the optimization of slow mixing RPM (velocity gradient). The experiments were performed with 20, 30, 40 and 50 RPM with velocity gradients $50 s^{-1}$, $90 s^{-1}$, $140 s^{-1}$ and $195 s^{-1}$. The optimized dose and the jar were used in this study. Results are given in Table 3 and Fig. 5.

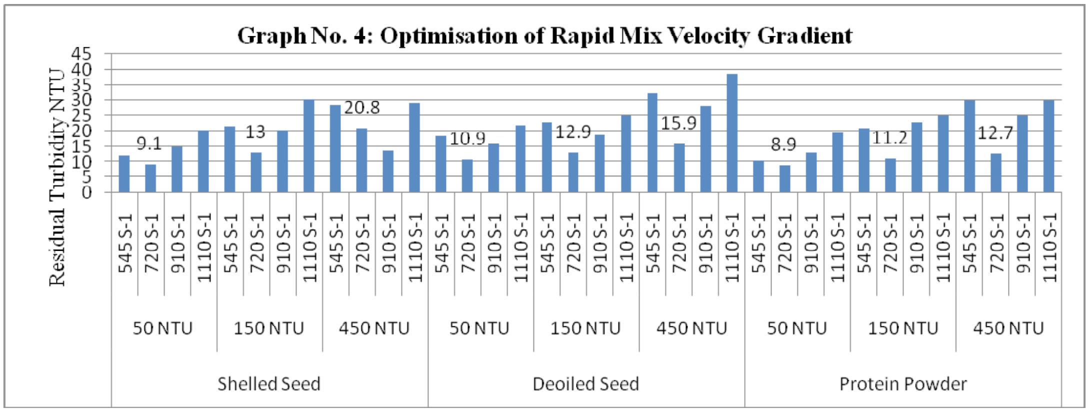


Fig. 4: Optimisation of rapid mix velocity gradient.

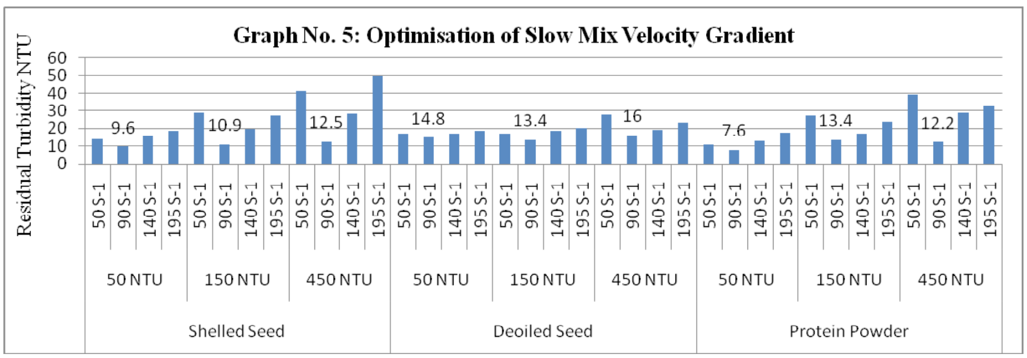


Fig. 5: Optimisation of slow mix velocity gradient.

RESULTS AND DISCUSSION

In our studies we found that the shelled seeds contain 36.9 % protein, 37.25 % fats and 16.38 % carbohydrates (Table 1). The aqueous extract of *Moringa* is far from being pure. It is a solution consisting principally of proteins, fats and carbohydrates. Dissolved organic carbon content was reduced by purifying the extract. First the oil content was removed using the ethanol as solvent and then the carbohydrates were removed by dialysis method.

As seen from the Figs. 1 and 2, the optimum dose of all types of extracts is minimum for bentonite clay turbidity. The dose is found to be decreased from shelled seed to protein powder. As the shelled seeds contain all carbohydrates, protein and fats, the dose of this extract is maximum, while in protein powder only active component is protein, the dose was found to be least. The optimum dose of all the forms of extract increased with increase in turbidity. It is because more active component is required to mode suspended solids.

From Fig. 3, it is observed that the circular baffled jar is the most efficient to remove all types of turbidity. It is evident from Fig. 3 that SB and CB showed less residual turbidities as compared to their non-baffled counterparts. Baffled jars were showing approximately 5% more turbidity removal than the non-baffled jars of respective types. More turbidity removal in case of baffled jars might be due to vortex formation immediately after the baffles leading to introduction of centrifugal forces. These centrifugal forces make them to move outwards and may make particles to settle down. Second reason might be the more interparticle collision because of turbulence created by baffles, leading to higher rate of agglomeration. So it was clear that baffled jars give higher rate of agglomeration, resulting into higher turbidity removal.

Although, the removal percentage changed somewhat with the type of jar applied, the optimal G value was the same for all combinations of jars.

The optimization of rapid mix velocity gradient was performed by considering four different velocity gradients. As seen from the Fig. 4, the minimum residual turbidity is observed at the rapid mix velocity gradient of $720s^{-1}$. Hence, the optimum value of the rapid mix velocity gradient is

Table 4: Optimisation of basin/container configuration, rapid mix velocity gradient and slow mix velocity gradient.

Type of Extract	Initial Turbidity (NTU)	Basin/Container Configuration		Rapid Mix Velocity Gradient			Slow Mix Velocity Gradient		
		Type of jars	Average residual turbidity (NTU)	RPM	Velocity gradient s^{-1}	Average residual turbidity (NTU)	RPM	Velocity gradient s^{-1}	Average residual turbidity (NTU)
Shelled Seed	50	CNB	18.1	100	545	12	20	50	13.9
		CB	6.9	120	720	9.1	30	90	9.6
		SNB	9.92	140	910	15	40	140	15.6
		SB	7.1	160	1110	20.3	50	195	18.8
	150	CNB	20.3	100	545	21.5	20	50	29
		CB	6.1	120	720	13	30	90	10.9
		SNB	23.0	140	910	20.2	40	140	19.9
		SB	9.9	160	1110	30.3	50	195	27.6
	450	CNB	17.5	100	545	28.5	20	50	41.3
		CB	6.5	120	720	20.8	30	90	12.5
		SNB	23.9	140	910	13.7	40	140	28.3
		SB	13.0	160	1110	29	50	195	49.9
Deoiled Seed	50	CNB	12.6	100	545	18.3	20	50	17
		CB	7.6	120	720	10.9	30	90	14.8
		SNB	18.0	140	910	15.9	40	140	16.9
		SB	8.3	160	1110	21.8	50	195	18.7
	150	CNB	16.4	100	545	22.9	20	50	17
		CB	6.8	120	720	12.9	30	90	13.4
		SNB	21.6	140	910	18.8	40	140	18.4
		SB	11.0	160	1110	25.1	50	195	20.1
	450	CNB	20.3	100	545	32.4	20	50	28
		CB	8.6	120	720	15.9	30	90	16
		SNB	26.3	140	910	28.1	40	140	19.3
		SB	11.0	160	1110	38.7	50	195	23.5
Protein Powder	50	CNB	10.1	100	545	10.3	20	50	10.7
		CB	7.4	120	720	8.9	30	90	7.6
		SNB	12	140	910	12.9	40	140	12.9
		SB	16.2	160	1110	19.8	50	195	17.8
	150	CNB	22	100	545	20.9	20	50	27.2
		CB	10.4	120	720	11.2	30	90	13.4
		SNB	20.1	140	910	22.8	40	140	16.9
		SB	17	160	1110	25.1	50	195	23.6
	450	CNB	24	100	545	30.2	20	50	39.5
		CB	15.2	120	720	12.7	30	90	12.2
		SNB	18	140	910	25.1	40	140	29
		SB	14.4	160	1110	30.2	50	195	33.3

(CNB - Circular Non-Baffled, CB - Circular Baffled, SNB - Square Non-Baffled, SB - Square Baffled)

720 s^{-1} for all the three types of extracts and for the three different turbidities.

Fig. 5 explains the results of the experiments performed for the optimization of slow mix velocity gradient. This result is in agreement with the work on *M. oleifera* by Muyibi & Evison (1995), who noted that the disturbance of floc formation occurs when the speed of rotation was increased to 60 rpm. It was again showing agreement to what has been said when rotation speed was increased from 40 rpm to 50 rpm. There was increase of around 30 % in the residual turbidity when rotation speed was changed to 50 rpm when compared to the results obtained at 30 rpm in all the initial turbidity samples. It is observed that for all types of coagulant extracts and turbidity, the optimum value of slow mix velocity gradient is 90s^{-1}.

CONCLUSION

The purpose of this study was to optimize the physical parameters of coagulation-flocculation in water treatment with *Moringa oleifera*. It is observed that the optimum dose of coagulant varies with the type and nature of turbidity. Also it is noted that the purified form of coagulant gave less dose as compared to its non-purified form. The shape and the baffles of the jars affected the turbidity removal efficiency. The circular baffled jars were found to be most efficient for all types of turbidities. The variation in rapid mix and slow mix velocity gradients showed the changes in turbidity removal efficiencies. The rapid mix velocity gradient of $720 s^{-1}$ and slow mix velocity gradient of $90 s^{-1}$ gave the maximum turbidity removal efficiency.

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