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Design of Water Treatment Units for Kumarakom Panchayath, Kerala

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***Abstract*—In Kumarakom Panchayath *(a local government in Kerala state, India)*, it is observed that the main causes of deterioration in water quality are due to the discharge of domestic wastes, municipal wastes and terrestrial runoff from seepage sites. So, it is necessary to design a water treatment plant for kumarakom Panchayath. A layout of the proposed plant was made consisting of various elements like Screens, Cascade aerators, Flash mixer, Clariflocculator, Rapid gravity filter and a Chlorinator. In this paper, we report the design of a flash mixer unit, rapid sand filter and a chlorinator for the plant. Initially, a physic-chemical analysis was done by collecting data regarding the quality of water in Kumarakom Panchayath.The parameters analyzed are pH, turbidity hardness, alkalinity, acidity, sulphates, chlorides, residual chlorine, nitrates, iron, dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), most probable number (MPN). Thereafter, a population forecasting was done based on survey details collected with which we could find the capacity of the treatment plant. So, based on the quality of water and capacity of the plant, we made a layout of the treatment plant. Finally, the design of the components was done.**

Keywords*—*Treatment plant, Flash mixer, Rapid sand filter

I. INTRODUCTION

Potable water is the fundamental need of man to sustain life. Present study aims to design a water treatment plant for Kumarakom panchayath based on characteristics of water and a schematic treatment plant layout was made using the analyzed data that would provide water to the individual residential lots, neighbourhood center, and utility tracts within the project area.[1] Thus, our work aims to make sure abundant purified water for all needs in the locality.

II. METHODOLOGY

A. Population Forecasting

Initially the population of the Panchayath was forecasted so as to get an idea about how the design of the treatment plant should be done. Geometric Mean Method of Population Forecasting was done here. The population data for the year 1991, 2001, 2011 and 2016 was collected. From these data using the Geometric Mean Method, the Population for the next decade was forecasted.[2-4].From the forecasted population, assuming a per capita water requirement as 120lpcd the peak water demand was calculated. Thus it was found out that the water treatment plant is designed with a capacity of 10MLD for 10 years. The TABLE I shows geometric method for population forecasting. The detailed calculation works involved is as follows.

TABLE I. GEOMETRIC MEAN METHOD FOR POPULATION FORECASTING

Year	Population	Increase in population in each decade	Percentage increase in population i.e., growth rate(ri)
1991	22500	500	2.22
2001	23000		
2011	27300	4300	18.69
2016	27600	300	1.09

Geometric mean of the growth rate is given by the following formula (1),

$$r = \sqrt[t]{(r1 \times r2\ \times r3)}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where, t = 2.5 and r = 2.5 √ (2.22×18.69×1.09) = 16.81

Assume design period of plant be 10 years. Therefore n = design period in decade = 1

$$Pn = P0\ \ (1 + r\ /100)^n\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where,

P_0 = last known population in the census = 27600
r = geometric mean of growth rate = 16.81
n = 1

We obtain, $P1$ = 32240

Assuming per capita water requirement as 120 lpcd, Total water demand = 32240 × 120
=3868800m3/day
= 3.86 MLD

Assuming a peak factor of 2.5,

Peak water demand = 3.86 × 2.5
= 9.6 MLD
≈ 10MLD

So the water treatment plant is designed with a capacity of 10MLD for 10 years

B. Analysis of Water Quality Parameters

The samples taken from the panchayath were tested in the laboratory. Table II shows the values of water quality parameters obtained after the analysis of the samples.

TABLE II WATER QUALITY PARAMETERS

2)

Sl. No	Parameters	Units	Observed Value	Acceptable Limit
1	Turbidity	NTU	3	5
2	pH	-	8	6.5-8.5
3	Acidity	mg/l	10	
4	Alkalinity	mg/l	51	200
5	Hardness	mg/l	417	300
6	Sulphates	mg/l	6.2	200
7	Chlorides	mg/l	96	250
8	Residual chlorine	mg/l	Nil	0.2
9	Iron	mg/l	Trace	0.3
10	Nitrates	mg/l	Trace	45
11	DO	mg/l	4.6	4
12	BOD	mg/l	5.93	30
13	COD	mg/l	12	250
15	MPN count	-	>1100	

3) Flash Mixer

C. Layout of Proposed Treatment Plant

A layout of the treatment plant was made consisting of various units such as screens, aerator, flash mixer, clari-flocculator, rapid sand filter and a chlorinator. The Fig.2 shows the components of Treatment Plant

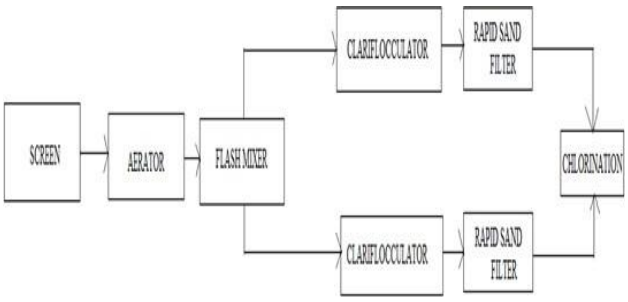

Fig.2. Components of Treatment Plant

1) Screening

Screening is the first operation at any water and waste water treatment works. This process essentially involves the removal of large non-biodegradable and floating solids that frequently enter a water works, such as rags, papers, plastics, tins, containers and wood.

Efficient removal of these constituents will protect the downstream plant and equipment from any possible damage, unnecessary wear & tear, pipe blockages and the accumulation of unwanted material that will interfere with the required water treatment processes.

Waste water screening is generally classified into either coarse screening or fine screening and they may be cleaned manually or mechanically.

Aerator

Aeration is done using cascade aerator. It is one of the oldest and most common type of aerator. It consists of a series of steps that the water flows over it similar to a flowing stream. In all cascade aerators, aeration is accomplished in the splash zones. Splash zones are created by placing blocks across the incline. Cascade aerators can be used to oxidize iron and to partially reduce dissolved gases. The Fig.2 shows the aerator.

Fig.2. Aerator

After screening out debris and testing raw water, chemicals that encourage coagulation are added to the water stream. The mixture is agitated quickly and thoroughly in a process called flash mixing. [5-7].The chemicals introduced into the water stream will attract any very fine particles, such as silt, that will not readily settle or filter out and make them clump together. These larger, heavier formations are called floc, which are much easier to remove from the water. The Fig.3 shows the flash mixer.

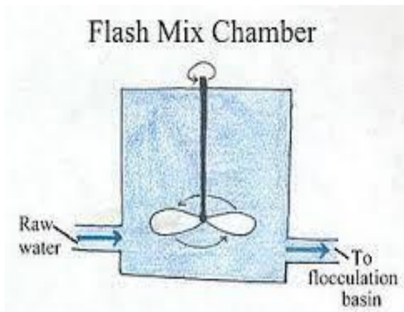

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Fig.3. Flash mixer

4) Clariflocculator

The clariflocculation is a chemical and physical water treatment process and it mainly consists in the removal of suspended substances. Its application is in the water treatment of surface water, industrial and municipal wastewater treatment, filtration pre-treatment, Reverse Osmosis, both in the municipal and industrial sectors.[8-10]

The clari-flocculation process is a traditional and consolidated treatment. The sequence of operations sedimentation-precipitation-coagulation-flocculation is the most common technique used in the world for the production of potable water. The process requires low costs for high volumes of purified water. It is a reliable process suitable for automatic control. The Fig.4 shows the Clariflocculator.

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Fig.4. Clariflocculator

5) Rapid Sand Filter

The rapid sand filter or rapid gravity filter is a type of filter used in water purification and is commonly used in municipal drinking water facilities as part of a multiple-stage treatment system. Rapid sand filters use relatively coarse sand and other granular media to remove particles and impurities that have been trapped in a floc through the use of flocculation chemicals—typically alum. The unfiltered water flows through the filter medium under gravity or under pumped pressure and the floc material is trapped in the sand matrix. The Fig.5 shows a Rapid sand filter.

Fig.5. Rapid sand filter

6) Chlorination

Water chlorination is the process of adding chlorine (Cl_2) or hypochlorite to water.[11-15] This method is used to kill certain bacteria and other microbes in tap water as chlorine is highly toxic. In particular, chlorination is used to prevent the spread of waterborne diseases such as cholera, dysentery, etc. The Fig. 6 shows the chlorine containers in chlorine room.

Fig.6. Chlorine containers stored in chlorine room

III. DESIGN UNITS

A. FLASH MIXER

Peak flow =416.6 m^3/hr

Assume detention time (D_t) =30sec

[Range between 20-60sec]

Volume of tank (V) = Flow x D_t .... (3)

We obtain the volume as 3.5 m^3

But, Volume = Area x Depth of tank

$$3.5 = \frac{\pi}{4} \times D2 \text{ x } 1.5\text{ D}$$

(Assume ratio of tank height to diameter =1.5:1)
[Range is 1:1 to 3:1]

D = 1.43 m ≈ 1.5 m
So, provide tank diameter of 1.5 m
Depth = 1.5 D = 1.5 x 1.5 = 2.25 m
Provide a freeboard of 0.2 m
Total depth = 2.25+ 0.2 = 2.45 m

<u>Power Requirements</u>

Power required (P) = $G^2\mu v$
Assume velocity gradient (G) = 600/sec [permissible limit > 300/sec]

Absolute viscosity (μ) = 0.798 x 10^{-3} NS/m^2 at 3° C

Volume to which power is supplied (V) = 3.5 m^3

P = $G^2\mu v$ = 600^2 x 0.798 x 10^{-3} x 3.5 = 1005.48 Watts

≈ 1005 Watts

Power per unit volume = $\left[\frac{1005}{3.5}\right]$

=287.14 Watts/m^3

Power per unit flow of water

= $\left[\frac{1005}{416.6}\right]$

= 2.41 Watts

Assume alum dosage to be supplied is 15 mg/l

Water to be treated = 10MLD =10 x10^6 l/day
Hence total requirement of alum

=15 x 10 x 10^6 mg/day x 365

= 5.475 x 10^{10} md/year

= 54750 kg/year

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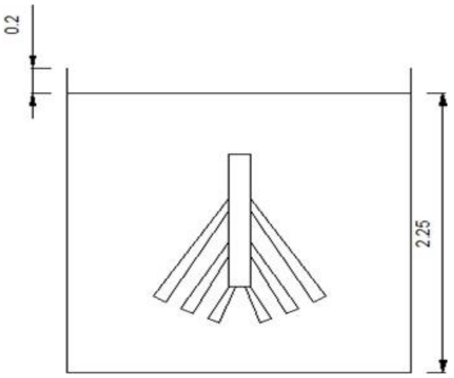

Fig.7. Design of flash mixer

B. RAPID SAND FILTER

Inflow to one Rapid sand filter =0.056m^3/sec

Step 1: Design of filter box

Assume quantity of backwash water is 3% of total wash filtered

Total water to be filtered = 204.134+ 204.134 x $\frac{3}{100}$

= 210.25 m^3/ hr

Actual filtration rate considering 30 min for backwash,

$= \frac{210.25 X 24}{23.5}$

= 214.73 m^3/hr

Assume filtration rate = 5000 l/hr /m^2

Therefore, area of filter bed = $\frac{214.73\frac{m^3}{hr}}{5000\frac{\frac{l}{hr}}{m2}} = \frac{214.73}{5}$

m^2 =42.9

=43m^2 (20-50 m^2)

Assume length to breadth ratio as 1.3:1 [Range is 1.2 to 1.33:1]

$\frac{L}{B} = \frac{1.3}{1}$

L = 1.3 B

Area = length x breadth

43= L x B

43 = 1.3 B x B

1.3 B^2 = 43

Therefore, B = 5.75 m and L

= 1.3 x B = 1.3 x 5.75

= 7.47m

Step 2: Design of sand media

Provide a media of 0.6mm size and uniformity coefficient of 1.4 to a depth of 60cm

$\frac{Qd^3h}{l}$ = B x 29323 (check for depth of media)

[Range:

Uniformity coefficient - 1.2 to 1.6

Effective sizes (d) - 0.35 to 0.7mm

Depth - 0.6 to 0.75 m]

Depth, $l = \frac{Qd^3h}{B\ X\ 29323}$

Assume height (h) as 2.5m

B = 4x10^{-4} (worst condition)

Q = 2 x filtration rate

$l = \frac{(5 X 2)X 0.6^3 X 2.5}{4 X 10^{-4} X29323}$ = 0.46 m = 46cm Given 60cm > 46cm.

Therefore safe

Step 3: Design of gravel bed

We are providing four layers Top layer = 2mm

Middle layer 1 =10mm

Middle layer 2 = 20mm

Bottom layer = 40mm

Using the equation,

l = 2.54 x k log d

where,

l = depth and

d = particle size

Assume k = 12 (range is 10-14)

l_{top} = 2.54 x 12 x log 2 = 9.17cm

l middle1 = 2.54 x 12 x log 10 = 30cm

l middle 2 = 2.54 x 12 x log 20 = 39cm

l bottom = 2.54 x 12 x log 40 = 48cm

Therefore ,

Total depth = 48cm ≈ 50cm

Depth of each layer

Top layer

Depth = 9.17cm ≈ 10 cm
Average size = 2 mm

Middle layer 1

Depth = 30- 9.17 = 20 cm
Average size = 10 mm

Middle layer 2

Depth = 39- 30 = 9 cm ≈ 10 cm
Average size = 20 mm

Bottom layer

Depth = 48 - 39 = 9 cm ≈ 10 cm
Average size = 40 mm

Step 4: Design of under-drainage system

i) Total area of perforation

Assume size of perforation = 10 mm

Assume $\frac{\text{total area of perforation}}{\text{total area of filter bed}} = 0.0025$
(Range is 0.002- 0.003)

Total area of perforation = 0.0025 x (L x B)

= 0.0025 x (7.47 x 5.75)

$= 0.1073\ m^2$

ii) Assume $\frac{\text{total area of perforation}}{\text{total area of lateral}} = x$

For 5mm perforation, ratio is 0.25
For 12mm perforation, ratio is 0.5
We need to find the ratio for 10mm perforation

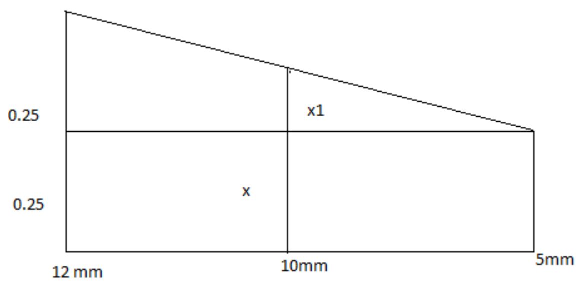

Fig.8. Calculation of X

$x = 0.25 + x_1$

$\frac{0.25}{7} = \frac{x_1}{5}$

$x_1 = 0.178$

$x = 0.25 + x_1 = 0.25 + 0.178 = 0.428$

$\frac{\text{total area of perforation}}{\text{total area of lateral}} = 0.428$

Total area of lateral $= \frac{\text{total area of perforation}}{0.428}$

$= 0.250\ m^2$

iii) Area of manifold = 1.5 to 2 times area of lateral

= 1.6 x area of lateral

= 1.6 x 0.250

$= 0.401 m^2$

Diameter of manifold

$\frac{\pi}{4} \times d^2 = \text{area}$

$\frac{\pi}{4} \times d^2 = 0.401$

Therefore, diameter = 0.714m ≈ 71cm

Provide 71cm ϕ piping

Assuming a spacing of 15cm for the laterals,

Total number of laterals = $\frac{\text{length}}{\text{spacing}} = \frac{7.47}{0.15} = 49.8 \approx 50$

Therefore number of laterals = 50

Area of one lateral pipe

$= \frac{\text{total area of lateral}}{50} = \frac{0.250}{50}$
$= 5 \times 10^{-3}\ m^2$

$\frac{\pi}{4} \times d^2 = 5 \times 10^{-3}$
Therefore diameter = 0.079m ≈ 79mm

Perforations

Given 10mm perforations,
Total area of perforation = $0.1073\ m^2$

Area of one perforation = $\frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times (10 \times 10^{-3})^2 = 7.85 \times 10^{-5}$ m

Total number of perforations $= \frac{0.1073}{7.85 \times 10^{-5}} = 1366.87$
≈ 1367

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 03, March-2021

Number of perforation in one lateral $= \frac{1367}{50}$

$= 27.34$

$= 28$

Length of one lateral = $\frac{B-0.71}{2} = \frac{5.75-0.71}{2}$

$= 2.52m$

Spacing of perforation $= \frac{2.52}{28} = 0.09m \approx 9cm$

(Spacing must be between 8-20cm)

Hence OK

71cm manifold is provided for a length of 7.47m.It is to be connected with 79mm laterals at a spacing of 15cm c/c .Each lateral should be provided with 10mm perforation at spacing of 9mm c/c providing one perforation at a cross section.

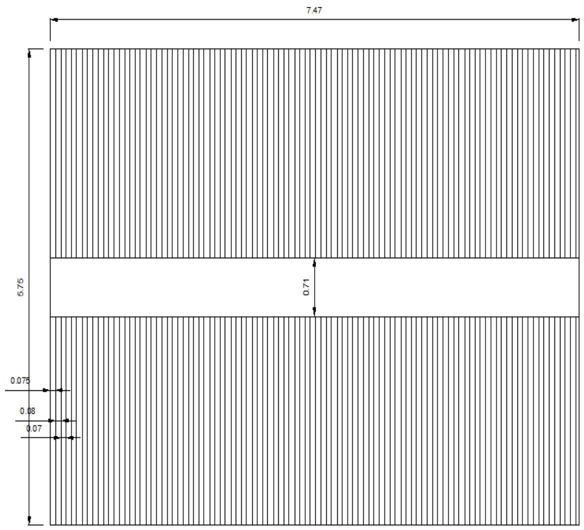

Fig.10. Design of under drainage system

Step 5: <u>Wash water trough</u>

Assume backwash water flow rate = 60cm/min = $60cm^3/min/cm^2$

Total quantity of water coming from the filter = Q

Using the equation,

$$Q = 1.376by^{3/2}$$

Q= 60cm/min = 0.6m/min = 0.6(7.47 x 5.75) m3/min

= 25.77/60

$= 0.429\ m^3/sec$

Align the wash water trough along the length of basin ,total of three numbers ,provided at a spacing of 1.5m c/c

So, in one trough ,Q = 0.429/3 = 1.36 x 0.4 x y $^{3/2}$ (assume b= 0.4)

y = depth of trough = 0.410m ≈ 41cm

Total depth of filter basin = 0.5m (freeboard) + 1.2m (water) + 0.6m (sand) + 0.5m (gravel) + 0.71m (manifold) =3.51m

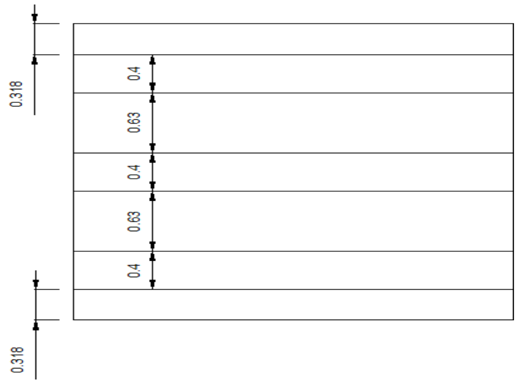

Fig.11. Design of wash water trough

Outflow from rapid sand filter, reducing 3% of sludge

$= 210.25 - \frac{3}{100} \times 210.25 = 204\ m^3/hr$

C. CHLORINATOR

Inflow to disinfection = 204 x 2 = 408 m^3/hr = 9.8MLD

Dosage of chlorine required to have 0.3mg/l of residue = 2mg/l

Assuming HOCl is applied to flash mixer

Quantity of HOCl provided = 2mg/l x 9.8 x 10^6 l/day

= 19.6 x 10^6 mg/day

= 19.6 kg /day ≈ 20kg /day

Using the equation,

$$C^{0.86}\, t_p = 6.3$$

Where,

tp = contact time which is the detention time

C= dosage of chlorine required to have 0.3mg/l of residue

Substituting value of C and tp in the above equation ,

$$2^{0.86}\, t_p = 6.3$$

Therefore t_p = 3.47min

Provide a safety factor of 2.5

Therefore, tp = 3.47 x 2.5 = 8.675 min ≈ 9 min

Volume = Discharge (Q) x Detention time(Dt)
= 408m^3/hr x 8.67
= $\frac{408}{60}$ x 8.675
= 58.99m^3 ≈ 60m^3

IV. RESULTS AND DISCUSSIONS

A. *FLASH MIXER*

Provide a tank of 1.5 m diameter and 2.45 m depth which includes 0.2m freeboard for flash mixing of chemicals.
Power required per unit volume of water = 2.41 Watts
Alum dosage to be applied = 15 mg/L
Therefore,
Total alum requirement for an year = 54750 Kg / year

B. *RAPID SAND FILTER*

Filter box

Inflow to one R.S.F = 0.056 m^3/sec
Total water to be filtered = 210.25 m^3/hr
Actual filtration rate considering 30min for backwash
= 214.73 m^3/hr

Area of filter bed = 43 m^2
Length of filter bed =7.47m
Breadth of filter bed = 5.75m
Sand media
Depth, l = 0.46m *Gravel bed*
Total depth = 50cm

i) Top layer

Depth = 9.17cm ≈ 10 cm Average size = 2 mm

ii) Middle layer 1

Depth = 30- 9.17
= 20 cm Average size
= 10 mm

iii) Middle layer 2

Depth = 39- 30 = 9 cm ≈ 10 cm
Average size = 20 mm

iv) Bottom layer

Depth = 48 - 39 = 9 cm ≈ 10 cm Average size = 40 mm

Under drainage system

Total area of perforation = 0.1073m^2
Total area of laterals = 0.250m^2
Area of manifold = 0.401m^2
Diameter of manifold = 71cm
Total number of laterals = 50
Area of one lateral pipe = 5 x 10^{-3}
Diameter of lateral pipe = 79mm
Area of one perforation = 7.85 x 10^{-5}m^2
Total number of perforation =1367
Number of perforation in one lateral = 28
Length of one lateral = 2.52m
Spacing of perforation = 9cm

Wash water trough

Total quantity of water coming from the filter

= 0.429 m^3/sec

Quantity of water coming from one filter if three filters are provided = 0.143 m^3/sec

Depth of trough = 41cm

Total depth of filter basin = 3.51m

Outflow from filter reducing 3% of sludge
=204 m^3 /hr

C. CHLORINATOR

Inflow to disinfection = 9.8 MLD

Dosage of chlorine required to have 0.3mg/l of residue = 2mg/l

Quantity of HOCl provided = 20kg /day
Detention time tp = 9 min
Volume of tank = 60m^3

V. CONCLUSION

The study concludes that lake water of study area was moderately polluted in respect to analyzed parameters. pH, total hardness, chloride and fluoride were found within permissible limit prescribed BIS. But the higher values of BOD and bacterial content in present study attributed lake water were not fit for drinking purpose. It is necessary to aware local villagers to safeguard the precious river and its surrounding. The concerned authorities should strictly monitor the quality of drinking water being supplied to the consumers to ensure public health. A majority of the people as well as the resorts here now buy drinking water. Those who can't afford to do that depend on the lake water and water supplied by the panchayat, which is not very regular. So a water treatment plant is designed to purify the lake water to potable water standards. The design of water treatment plant is done by conventional method of water treatment plant design by assuming some constant values involves processes that alter the chemical composition or natural "behavior" of water. A coarse strainer including a removable basket screen with 50 to 100 mesh, is positioned at the intake point of surface water to remove larger particulate matter and this water is fed to the raw water tank. Treatment steps include the addition of chemical coagulants (clotting agents), pH-adjusting reagent chemicals that react to form floc. Floc then settles using the force of gravity into settling tanks or is removed as the water percolates through gravity filters. The clarification process is designed to removes particles larger than 25 microns.

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