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# Analysis of the Flocculation Process in Purification of Environmental Waters During Dry and Wet Seasons in The West African Countries

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**An investigation of the performance of flocculators in the city of Dimbokro, Cote d'Ivoire was conducted. The correspondence between theoretical and experimental hydrodynamic and design parameters of the performance of flocculators with propeller mixers was reviewed according to Camp's criterion. Recommendations are provided on the operation of flocculators with the goal of intensifying the coagulation process and energy conservation.**

**Key words:** Flocculator, Propeller mixers, Energy savings, Camp's criterion, the dimensionless criterion GT.

On 17th-20th of February 2014 the XVII conference of African Water Association (Association Africainede l'Eau – AAE) was held in Abidjan, Cote d'Ivoire. The topic of the conference was "Mobilization of Resources and Management of Water Supply and Sanitation in Africa". During the conference the African countries discussed the following issues:

a) Flood forecasts and protection of water resources in Africa;
b) Evaluation and modeling of the effects of climatic changes;
c) Strategy of intensification of water and health services;
d) Water purification technologies;
e) Application of technologies adapted for African conditions;
f) Services of water allocation for the indigent;
g) Academic research and development of wastewater purification technologies;
h) Payment for water: allowance for the indigent;
i) Financial support of the Water project;
i) Introduction of new means of water purification for sparsely populated areas;
j) Financial support of the water supply and sanitation development program and partnerships between private and state investors;
k) New methods of pool protection;
l) New method of wastewater treatment.

The main purpose of the conference is improvement of the water supply and sanitation system.

One of the aspects of the improvement of water supply systems is regulation of the coagulation process in environmental water purification with the goal of supplying water, while

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taking into account the change of seasons and the corresponding changes of temperature and humidity which are common for all West African countries. Our research was conducted on the basis of the water supply system in Dimbokro, Cote d'Ivoire, which is a typical example for this region. According to the temperature change in the city of Dimbokro 4 main seasons can be distinguished: the "dry" season (December – March and August - September); rainfall season – the "wet" season (April - July and October - November)[1]. Different water temperature corresponds to different seasons: T = 30.40°C (19/04/2006, rainfall season) and T = 27.40°C (03/03/2008, the "dry" season)[2]. Hence the goal of this article is investigation of technological operating modes of the flocculators at the water treatment plant in the city of Dimbokro, Cote d'Ivoire throughout the year, i.e. during the "dry" and the "wet" seasons, because significant changes occur in climatic conditions and in the source water quality.

## EXPERIMENTAL

Flocculation occurs in special tanks – flocculators – which are equipped with propeller mixers[3]. The driving element of a propeller mixer is a 3-bladed or a 4-bladed propeller, installed on a vertical axis and directly driven by a geared motor, usually with a rotation speed controller[3]. The mixing system, the flocculator volume and the amount of energy dissipated within vary depending on its purpose and on the characteristics of the treated water.

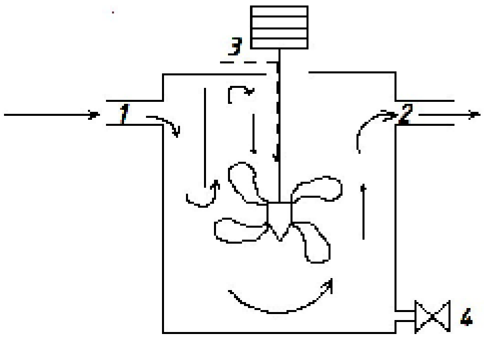
Processing parameters of the flocculator, where previously coagulated water enters, are characterized by the following figures: velocity gradient G in $s^{-1}$, contact time T in minutes, terminal local velocity of the liquid and floccules[3]. Thus the design of the treatment apparatus should ensure preservation of floccules throughout their movement from the flocculator to the area of settling or flotation.

Depending on the quality of the treated water, the velocity of surface water transition to the clarifier is adapted to the properties of metal hydroxide floccules (Fe and Al) and equals V d" 0.20 m/s for unsteady floccules, Vd" 0.50 m/s for hard floccules[3].

In practice two types of flocculators are mainly used:

1. Flocculators equipped with a mixing device (with mechanical mixing).
2. Flocculators with deflector plates (baffled flocculators) [3].

The water treatment plant in Dimbokro is equipped with two flocculators in the form of rectangular tanks of reinforced concrete which are equal in area, volume and height: $S_{floc.} = 14\ m^2$; $V_{floc.} = 38\ m^3$; $”_{floc.} = 2.71$ m. Each flocculator is equipped with a propeller mixer (fig. 1). The calculated time the water stays inside flocculator is T = 39 min [2].




1 – initial wastewater delivery pipe; 2 – clarified water diversion pipe; 3 – reagent delivery; 4 – tank emptying.

**Fig. 1.** Flocculator with a propeller mixer

It is known that flocculators are designed to create favorable conditions for the second (closing) stage of coagulation – flocculation – which is facilitated by smooth mixing of the flow[4]. Efficiency of the process increases with slow and steady mixing of water which creates optimal conditions for agglomeration of small floccules into large ones[5].

Using Camp's criterion, let us define the optimal parameters for a flocculator with a propeller mixer in the Dimbokro water treatment plant.

Water consumption Q = 2500 $m^3$/day = 0.0289 $m^3$/s; average temperature during the rainfall season (19/04/2006) – 30.40°C [2;1], coefficient of volume utilization Kset = 0.5 [6].

The time the water stays in the flocculation tank is calculated according to the following formula:

$$T = \frac{LBH}{Q}, s \qquad ...(1)$$

where Q is wastewater consumption in

$m^3/s$; L is the tank length in meters; B is the tank width in meters; H is the tank depth in meters.
LBH = $V_{floc.}$ = 38 $m^3$.

$$T = \frac{38}{0.0289} = 1314.87 \text{ or 22 min.}$$

Properties of the propeller: rotation radius is $r_1 = r_2 = 0.35$ m; rotation rate is $n_1 = n_2 = 15$ $min^{-1}$; length is $l_1 = l_2 = 1.40$ m; width $b_1 = b_2 = 0.35$ m; motor power is 1.1kW.

Knowing cross-section area of the flocculator ($S_{floc.}$ = 14$m^2$), let us calculate the propeller area f:

f = lbmp, $m^2$, ...(2)

where m is the number of propellers in a flocculator, m = 1; p is their number, p = 4.
f = 1.40*0.35*1*4 = 1.96 $m^2$.

The total vertical area of a blade should not be more than 15÷20% of the cross-section area of the tank, otherwise there is a possibility of rotation of the whole mass of water without the necessary speed gradients [5].

Ratio of propeller area (f) in $m^2$ to cross-section area of the tank ($S_{floc}$) in $m^2$ is:

$$\frac{f}{S_{floc}}*100 = \frac{1.96}{14}*100 = 14\%, \quad ...(3)$$

i.e. it is less than the maximum value, thus the present proportions satisfy the hydrodynamic requirements for the optimal flow movement.
The average speed of movement of water near the rotating propeller $V_1$ is around ¼ of the propeller speed V [5].

The difference of moving water speed and propeller speed ΔV is:

$\Delta V = V - V_1 = 4V_1 - V_1 = 3V_1$ ...(4)

Then ratio of the difference between propeller linear speed and moving water linear speed is:

$$\frac{\Delta V}{V} = \frac{3V_1}{4V_1} = 0.75 \quad ...(5)$$

Relative propeller moving speed with rotation radiuses:

$$V = \frac{n \cdot 2\pi r \frac{\Delta V}{V}}{60}, \frac{m}{s} \quad ..(6)$$

with rotation rate $n_1 = 15 min^{-1}$:

$$V_1 = V_2 = \frac{15*2*3.14*0,35*0.75}{60} \frac{24.7227}{60} = 41.21 \text{ Am/s.}$$

Let us define the power N, required to put one propeller in motion, according to the following formula:

$$N = 51C_D fV^3, kgF \cdot \frac{m}{s} \quad ...(7)$$

where CD is the coefficient of water resistance which depends on the ratio of propeller length l to its width b and equals 1.2 while $\frac{l}{b} = \frac{1.40}{0.35} =$; f is propeller area in $m^2$; V is propeller moving speed relative to water in m/s.
N = 51*1.2*1.96*0.41 = 8.39 kgF.m/s.

In order to simplify the calculations and considering the fact that most countries in the world employ the International System of Units, let us translate various calculated parameters of Camp's criterion from CGS to SI [7]:

1 kgF m/s = 9.81 W, i.e. N = 8.39*9.81 = 82.30 W.

Let us calculate specific power consumption W in $kgF \frac{m}{m^3}.s$ for 1 $m^3$ of the flocculator in CGS:

$$W = \frac{N}{V_{floc}}, kgF \frac{m}{m^3}.s, \quad ...(8)$$

$$W = \frac{8.39}{38} = 0.22 . kgF \frac{m}{m^3}.s$$

In SI:

1 $kgF \frac{m}{m^3}.s$ = 9.81 W/$m^3$, i.e. W = 0.22*9.81 = 2.16 W/$m^3$.

If the time of mixing is 22 minutes, the minimum required power of the mixer is (2.16 W/m3 x 38 m3 x 60 / 22) = 223.67 W-h = 0.22 kW-h.

The installed electric motor's power of 1.1 kW exceeds the required power (1.1/0.22) by 4.9 times, i.e. can be considered as 0.5 kW considering the coefficient of safety.

Let us check the correspondence between hydrodynamic and design parameters of the functioning of flocculators with propeller mixers and the actually required parameters according to Camp's criterion G [5]:

$$G = 10\sqrt{\frac{W}{\mu}}, s^{-1} \quad ...(9)$$

where W is the energy spent on mixing the water per unit of volume of water in the flocculation tank, measured in kgF·m/m³·s; μ is the absolute water viscosity measured in poise (g.sec/cm²); while T = 30.40°C - μ = 0.008 poise [8,9].

1 poise = 0.1 Pa·s, i.e. μ = 0.008* 0.1 = 0.0008 Pa·s = 52.41 $s^{-1}$.

The value of G = 52.44 $s^{-1}$ is within the recommended limits: 25 - 65$s^{-1}$ [5].

According to Lamp, the rate of flocculation is proportional to the value of G: the greater is this criterion, the less time is required for flocculation[4], hence Camp introduced a dimensionless criterion of this process Ke, defined by the following formula:

$$Ke = GT, \quad ...(10)$$

Ke = 52.41*22*60 = 69 181.2 (while n = 15 $min^{-1}$).

Thus the value of the dimensionless criterion of the flocculator mixer mode of operation in the rainfall season is within the recommended limits (40 000- 210 000) [5].

Next let us define the minimum and the maximum propeller rotation speed n, which corresponds to dimensionless criterion Ke which is within the recommended limits.

To achieve this we vary propeller rotation rate n from 1 to 32 $min^{-1}$ (fig. 2).

While rotation rate n = 11 $min^{-1}$ and n = 31 $min^{-1}$ the approximate value of GT is 43564.87 and 206105.68 respectively.

Let us find the yearly energy required to put the propeller in motion. According to (10), while rotation rate n = 11 $min^{-1}$; n = 15 $min^{-1}$ and n = 31$min^{-1}$, the required electric motor power N equals 0.03 kW, 0.08 kW and 0.73 kW respectively. Let us find energy consumption. Under the condition that flocculation tank volume is $V_{floc.}$ = 38 m³, if the time of mixing is 22 min, the minimum propeller power is kW-h: (0.03E24) – 0.72 per day; 21.6 per month; 259.2 per year. Similarly, if n = 15 $min^{-1}$ it is (0.08E24) – 1.92 per day; 59.5 per month; 714.2 oer year; if n = 31$min^{-1}$: (0.73E24) – 17.5 per day; 420.5 per month; 5045.8 per year.

According to diagram (fig.2), the minimum propeller rotation rate n = 11 $min^{-1}$ and the maximum ration rate $n_{max}$ = 31 $min^{-1}$ correspond to dimensionless criterion GT = 43564.87 and GT = 206105.69.

Based on the deduced information the following recommendations on energy saving can be given in case of flocculators operating when water temperature T = 30.40°C:

– time of water staying T = 22 min;

– propeller rotation rate n is under 11 – 31 $min^{-1}$ (fig. 2); for better energy saving $n_{min}$ = 11 $min^{-1}$.

Let us follow the change in criterion G within the accepted limits of 25-65 $s^{-1}$ [5] with the minimum and the maximum water temperature. To do this let us vary water temperature T from 200°C (the minimum water temperature) to 450°C (the maximum water temperature). Based on the calculations let us make the diagram of relation between criterion G and water temperature T (fig. 3).

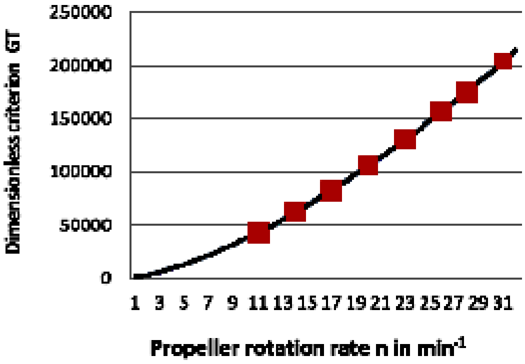



**Fig. 2.** Correspondence between dimensionless criterion GT and propeller rotation rate n

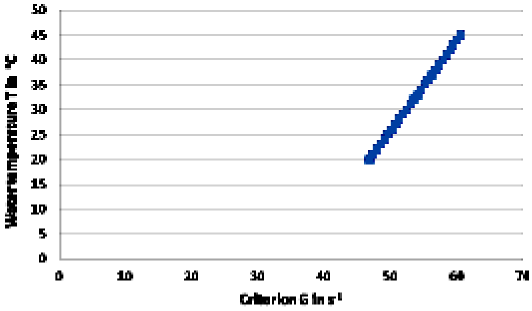



**Fig. 3.** Correlation between criterion G in $s^{-1}$ and water temperature T in °C

While water temperature T = 27.40°C (03/03/2008, the "dry" season), the approximate value of G = 50.75 $s^{-1}$, and while water temperature T = 30.40°C (19/06/2006, the "wet" season), the value of G = 52.44 $s^{-1}$. For a deep cleaning is recommended to use natural zeolites and activated carbons[10-20].

## CONCLUSION

Based on the conducted research a general conclusion can be made that rotation rate n ($min^{-1}$) does not depend on seasons (the "dry" and the "wet" seasons). Considering the issue of energy saving it is recommended to use propeller rotation rate n = 11$min^{-1}$ for any season of the year and the time of water staying T = 22 min.

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