DATE: Aug. 25, 1988

TO: Office Engineers

FROM: A. R. Hammer, P.E., Director
Division of Water Supply Engineering

THRU: E. H. Bartsch, P.E., Director
Office of Water Programs

SUBJECT: Water - Design - Calculations - Water Horsepower and Mean Velocity Gradient

Delete: IIIc 6a and IIIc 6b

Attached are two memoranda that are being reissued with an arabic number so all working memoranda are in the same numbering system.

ARH/djv

Date: 14 November 1975

TO; E. H. Bartsch

From: M. B. Woods

Subject: Water - Calculations
Determination of mean velocity gradient C in open channels and through sluice gates.

The mean velocity gradient due to friction caused by flow is calculated by the formula:

$$G = \frac{62.4\ 11}{U\ T}$$

where:

H is the head loss due to friction in feet
U is the viscosity of water in pound-seconds/sq. ft.
T is the detention time in seconds

The determination of H in this formula presends a problem in critical areas. Whitman, Requardt and Associates has used the manning formula and calculated a friction slope. This approach can be used only in open channel flow with constant channel conditions because the value of S in this formula is the bed slope, -dz/dx. The head loss can be calculated from the frictions slope, -dH/dx. The only time these two values are equal is when flow is at uniform depth, y_o

In other words: $-dz/dx = -dH/dx$
if $y = y_o$

However, if it is calculated at a constriction or a sluice gate then the channel conditions are not constant or gradually varying and

$$-dx/dx = -dH/dx$$

According to Dr. Wiggort of VPI & SU, the head loss through a sluice gate would probably be negligible but the conditions downstream from the sluice gate, i.e. hydraulic jump, would cause some head loss. He stated that an orifice equation such as

$$H = K \frac{V^2}{2g}$$

may be appropriate. He then referred me to pages 202 and 208 of Open Channel Flow which indicated two types of discharge under a sluice gate. He said you would have to know if the flow downstream of the sluice gate is "free outflow" as on page 202 or "drowned outflow" as on page 208.

It is my conclusion that a direct measurement and the use of the origice equation would be the simplest way to calculate H. It should be pointed out that use of the manning formula is completely erroneous. This was also Wiggert's opinion.

DATE: 2 April 1976
TO: Messrs. Sutherland, Brown, Capito, Conner, Haley and Hammer

From: E. H. Bartsch

SUBJECT: Water - Design - Calculation of Water Horsepower and Mean Temporal Velocity Gradient Induced by a Mechanical Mixing Device

In the past, the Bureau Policy in calculating water horsepower and mean temporal velocity gradient for a mechanical mixer with a series of mixing paddles has been to determine the effective radius arm to the centroid of the entire series of paddles on the mixing arm. This value was then used to turn to calculate the relative velocity of the paddles to the velocity of the fluid. Recent information indicates that this method is not as accuratge as calculating the water horsepower for each paddle on the mixing arm and adding them together for the total water horsepower of the mixing device. Therefore, in the future, it will be the policy of the bureau to use this more accurate methodology for calculating water horsepower and mean temporal velocity gradient. The following equations are used in these calculations.

$$P = 1/2\ C_d pAv^3$$

where
P = water horsepower (ft-lb/sec)
C_d = coefficient of drag (dimensionless)
A = paddle area (square feet)
p = mass density of water = _____(pound-seconds/square feet)
v = 2 (1-k) rn/60
where v = ratio of impeller velocity to fluid velocity = 0.2 - 0.3 (dimensionless)
r = effective radius to area centroid (feet)
n = revolutions/minute

Therefore combining these two equations

$$P = 5.741 \times 10^{-4}\ C_d\ p\ ((1-k)n)^3\ r^3 A$$

If a series of paddles are involved, then r^3A is replaced with r^3A

also $G = \left(\frac{P}{u\ V}\right)^{1/2}$

where G = mean temporal velocity gradient (seconds^{-1})
V = tank volume (cubic feet)
U = absolute viscosity of water (pound-seconds/square feet)

Example problem

n = 2.01 rpm
p = 1.938 lb-sec/ft^2
C_d = 1.8
k = .25
length of paddles = 10.34
V = 5990 ft^3
U = 2.1×10^{-5} lb-sec/ft^2

old method - calculate r and total A

$$r = \frac{r_n A_n}{An}$$

$$r = \frac{(10.34)(6"\ 11.25) + 6"\ (3.25) + 6:\ (5.25) + 6"\ (7.25) + 6"\ (9.25)}{10.34\ (30")}$$

r = 5.25 ft.

$$P = 5.741 \times 10^{-4} (1.8)(1.938)(1-.25)2.01)^3 (5.25)^3 (51.7)$$
$$P = 51.33 \text{ ft-lb/sec.}$$

$$G = \left[\frac{51.33}{(5990)(2.1\times10^{-5})}\right]^{1/2}$$

new method - calculate r^3A for each paddle and sum.
Then substitute into the same equation

$$r^3A = (1.25)^3(10.34) + (3.25)^3(10.34) + (5.25)^3(10.34) + (7.25)^3(10.34) + (9.25)^3(10.34)$$
$$= 13995 \text{ ft}^5$$
$$P = 5.741 \times 10^{-4} (1.8)(1.938)(1-.25)2.01^3(13995)$$
$$P = 96.02 \text{ ft-lb/sec.}$$

$$G = \frac{96.02}{(5990)(2.1\times10^{-5})}$$

$$G = 27.6 \text{ sec.}^{-1}$$