UMIVERSITY OF MICHIGAN
DEPARTMENT OF MECHANICAL ENGINEERING
CAVITATION AND MULTIPHASE FLOW LABORATORY

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WET STEAM TUNNEL: HISTORY OF DROPLET MOTION

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INTRODUCTION:

This paper is a part of the wet steam tunnel research program which investigates the motion of secondary droplets behined a stationary turbine blade.These secondary droplets are produced from a thin liquid film which forms on the stationary blade due to the accumulation of primary droplets which are carried in the steam that enters the turbine.

The secondary droplets have a much greater mass than the primary droplets.Thus, a greater kinetic energy is encountered in their motion.Prevention of turbine blade errosion which is mainly caused by the collision of the secondary droplets with the blades is the main motive of this research program.

WORK PERFORMED:

In the past semesters,the raw data were collected by analyzing the films which were taken and shot using a Fastex camera and an intense lighting source.The Fastex camera runs at 5000 frames per second.

Previously,a computer program was used to put the raw data into form of tables.These tables contain information for the motion of 327 droplets.Test conditions were kept fixed for all droplets except two.First,the flow rate of water that was injected through the upstream slot across the blade to provide the film;and second the steam velocity entering the tunnel.

During this semester, these tables were used to make plots (accompanied with this report) which represent the the history of motion of these secondary droplets.

NOMENCLATOR:

D_o =initial diameter of the droplet.

D =instantaneous diameter of the droplet.

m_o=initial mass of the droplet.

m =instantaneous mass of the droplet.

T =dimentionless time; $tU_s/D_o(\rho_s/\rho_w)^{1/2}$.

U_s=steam velocity.

ρ_s=steam density.

ρ_w=water (droplet) density.

t =real time (0.001 sec. intervals, i.e., data taken from every fifth frame of film).

$\overline{X}$ =dimentionless distance; x/D_o .

x =instantaneous real distance (position of the droplet from the end of the blade).

$\overline{X}_b$ =same as $\overline{X}$, when breakup occures.

T_b =same as T, when breakup occures.

$\overline{X}_b/T_b^2$ =dimentionless acceleration.

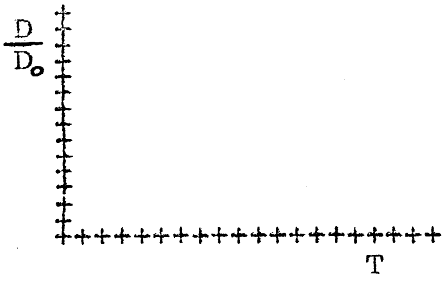
W_e =Weber number; $(\rho_s U_s^2 D_o)/\sigma_d$

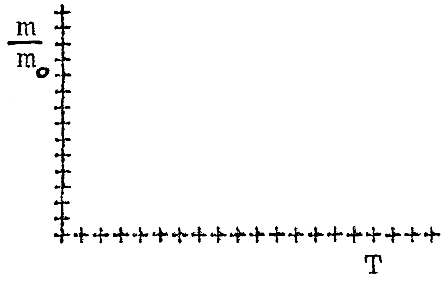
σ_d =surface tension of droplet.

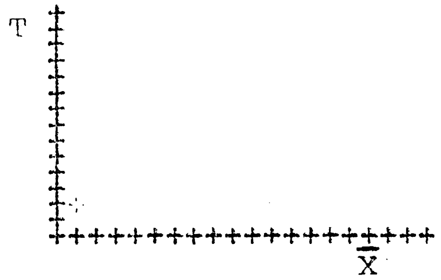
t_b=same as t, when breakup occures.

P_d =dynamic pressure; $(\rho_s U_s^2)/2$.

The following plots were made for each droplet.



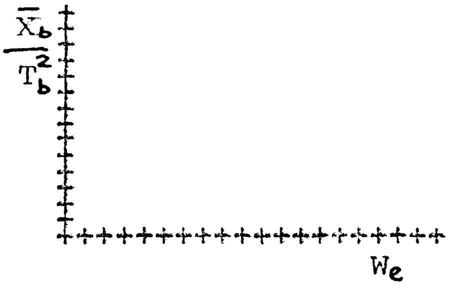


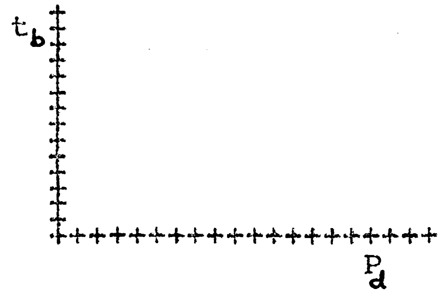


It also,is necessary to note that some of these droplets breakup into much smaller drops after they leave end of the blade.If this can happen all the time (breakup into smaller droplets),the errosion effects will be reduced considerably,because of the smaller mass involvement.

Many droplets analized so far followed this breakup procedure.Of course it is desired to reduce as much as possible the distance from end of the blade,at which the droplet breakes up,so that the large (secondary) droplets will not reach the next row of blades.Therefore only a certain area,(starting from end of the stationary blade and spreading in the direction of steam flow) which can be focused by the camera is important.This means ,that breakups of more droplets might be noticed further away from the end of the blade, if their motion is traced for a longer time,but it would not be of much importance to us.

The following plots were made only for the droplets that broke up.





RESULTS AND CONCLUSIONS:

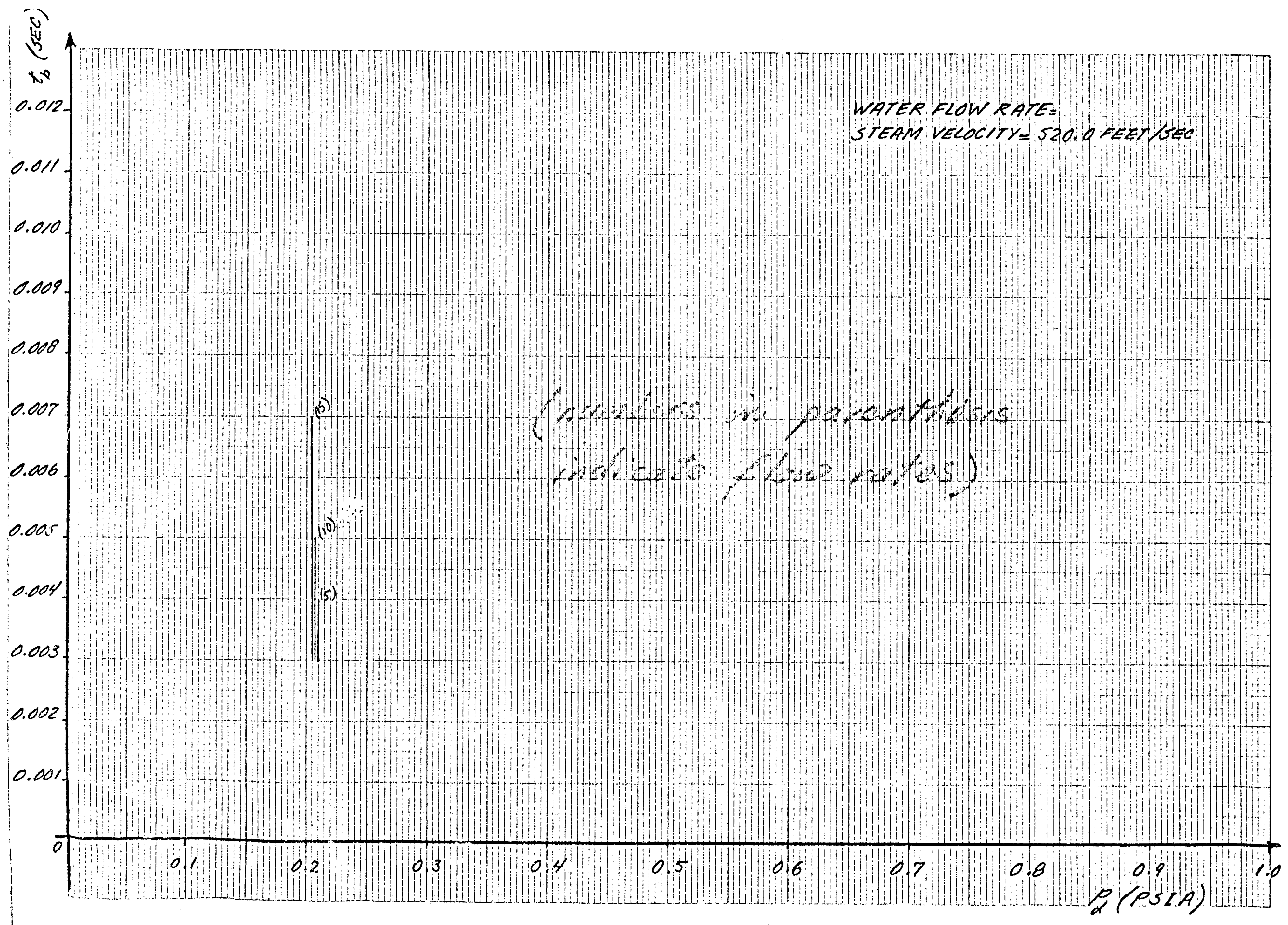
From plots of (D / D_o) vs. T,it is observed that for a fixed steam velocity,an increase in the flow rate of water does not make any changes in the (D / D_o) ratio.Also it is observed that an increase in the steam velocity,also increases the (D / D_o) ratio ;this increase is from 1 (for 305 f/s),to 1.9 (for 975 f/s).A point must be noted here is that for 1100 f/s (steam velocity),this ratio starts to decrease to 1.5.

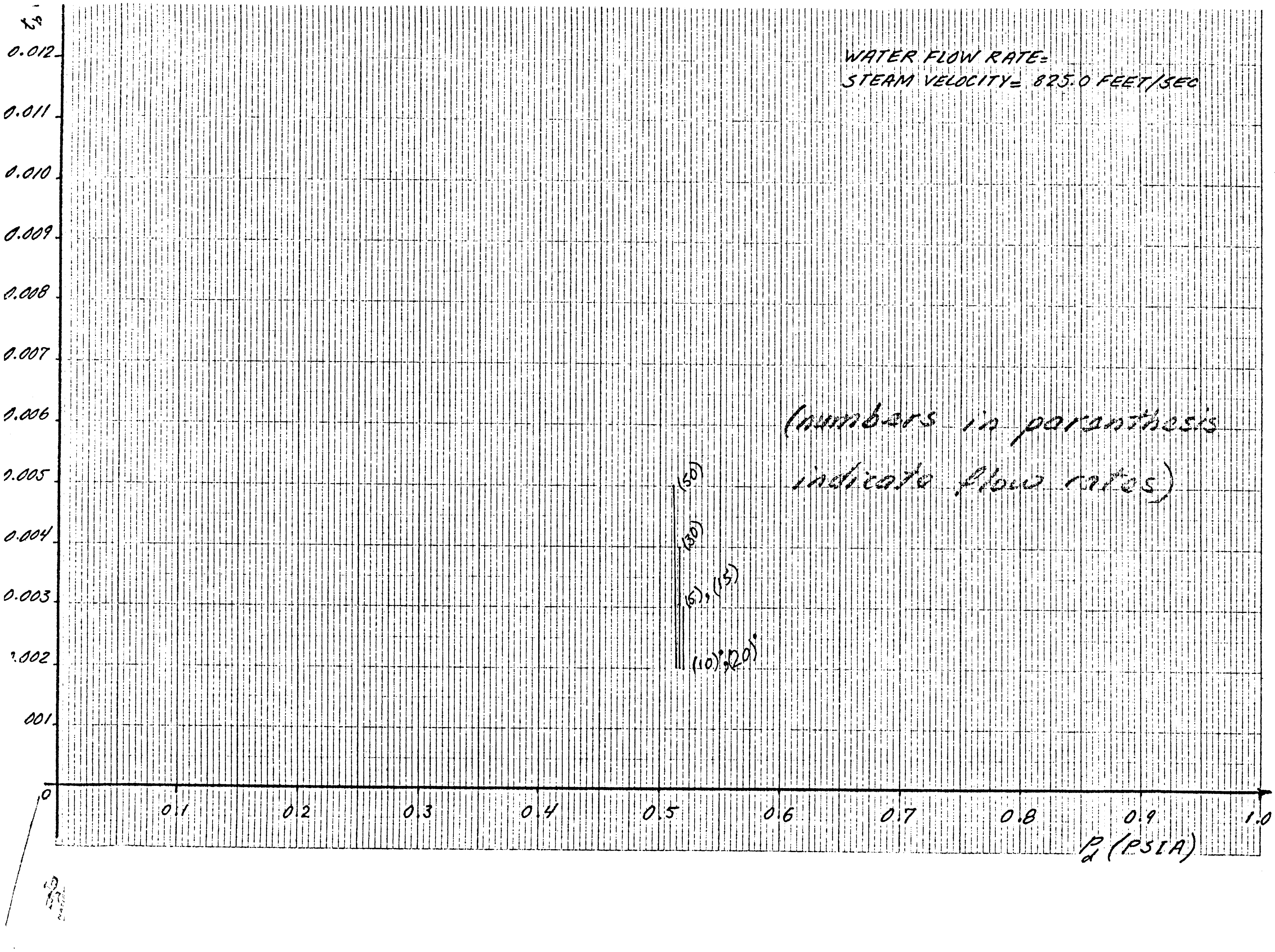
From plots of (m/m_o) vs. T, it is observed that for a fixed steam velocity, an increase in the flow rate of water does not make any changes in the (m/m_o) ratio. Also it is observed that an increase in the steam velocity, also increases the (m/m_o) ratio; this increase is from 1.5 (for 305 f/s), to 3.0 (for 1100 f/s).

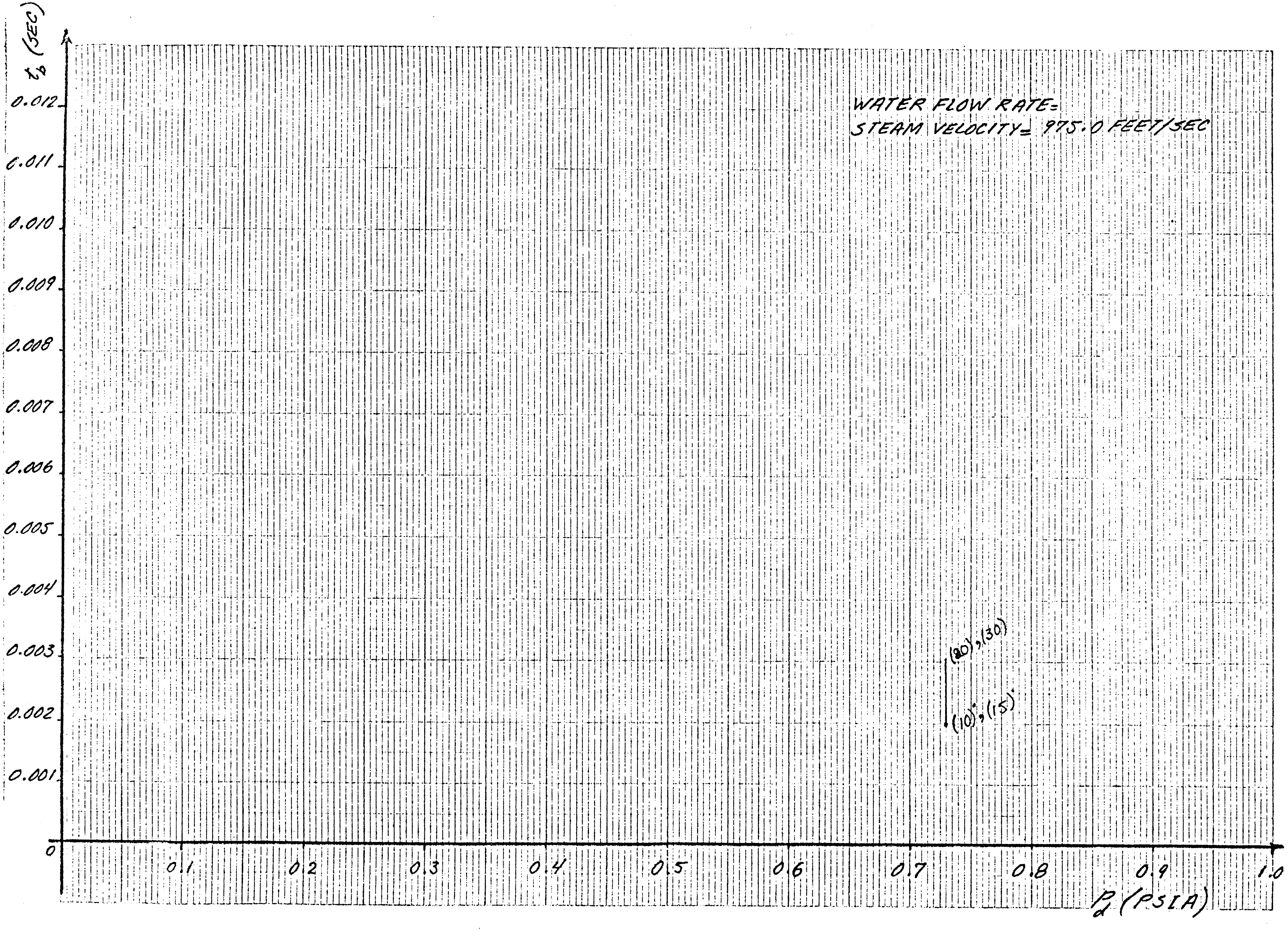
From plots of T vs. $\bar{X}$, it is observed that for a fixed steam velocity, an increase in the flow rate of the water does not have any effect on the velocities of the droplets. It is also observed that the droplet velocities are increased as the steam velocity is increased, also the breakup distance (for the droplets that broke up) is increased slightly as the steam velocity is increased.

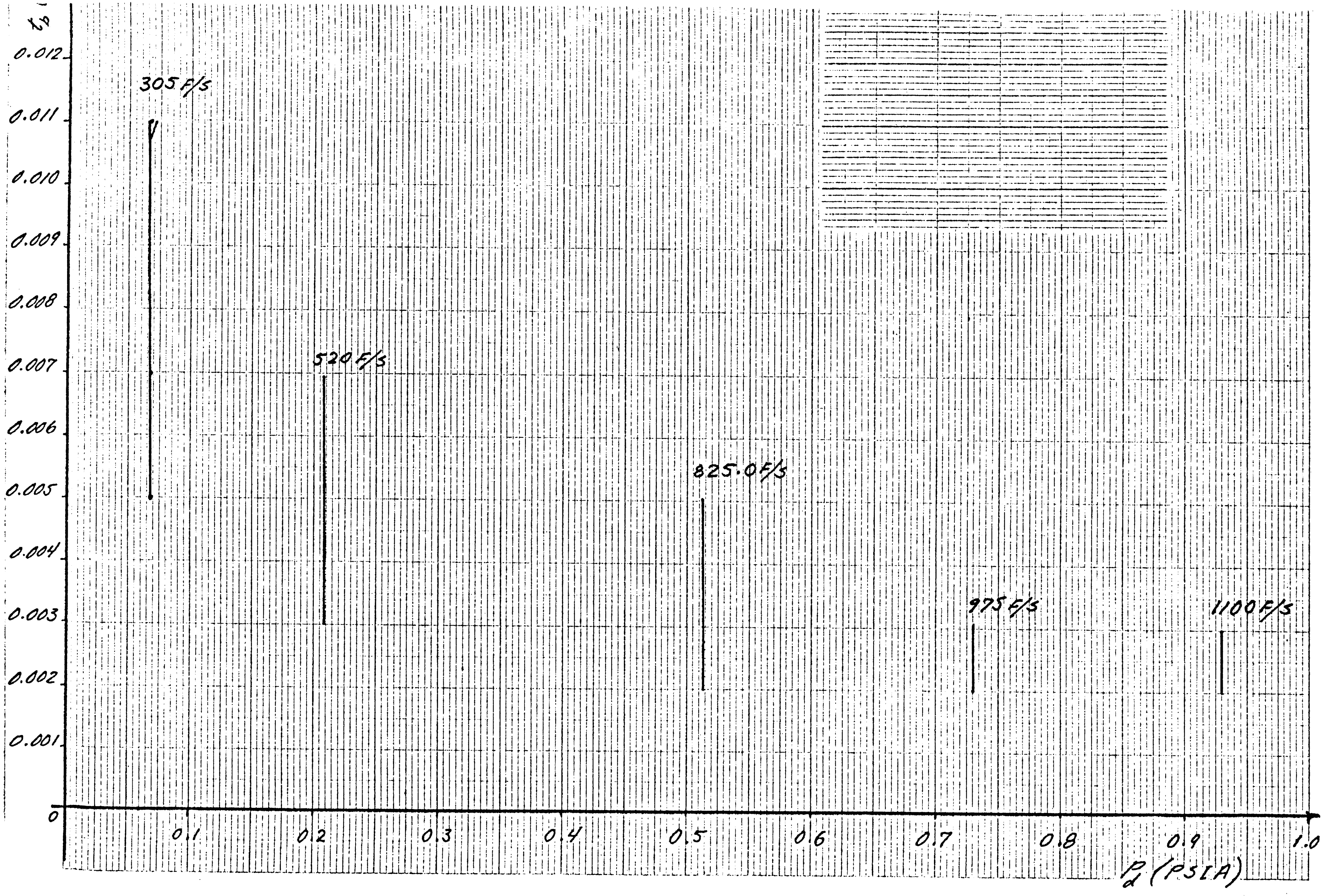
From the plots of t_b vs. P_d, it is observed that for a fixed steam velocity, break up time increases as the flow rate of the water is increased. Considering the different steam velocities, break up time is decreased as the steam velocity is increased, which also increases the dynamic pressure.

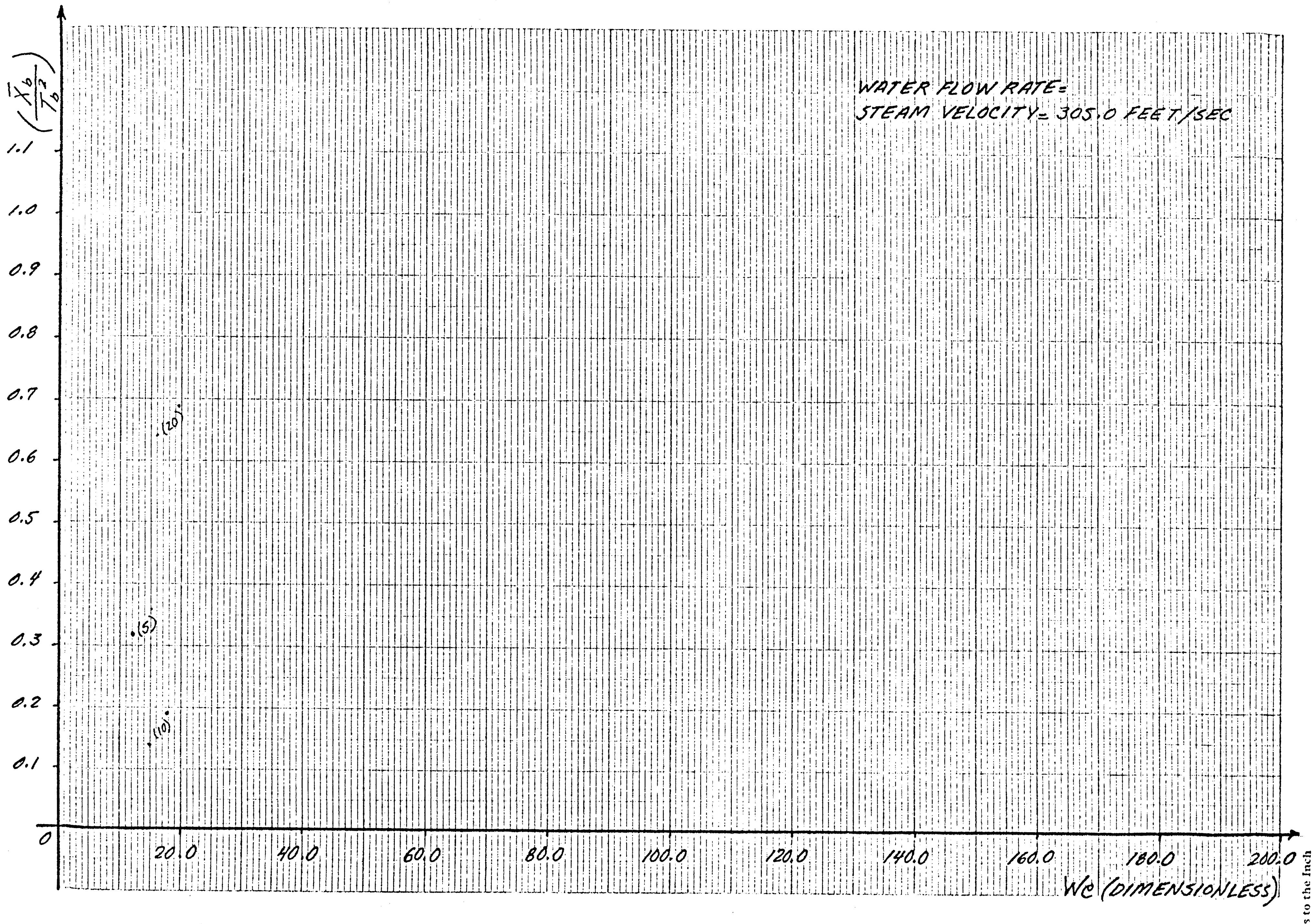
From the plots of $(\bar{X}_b/ T_b^2)$ vs. W, it is observed that for a fixed steam velocity, acceleration decreases with an increase in the flow rate of the water. Also it is observed that as steam velocity is increased, acceleration (dimentionless) decreases and Weber numbers are increased.

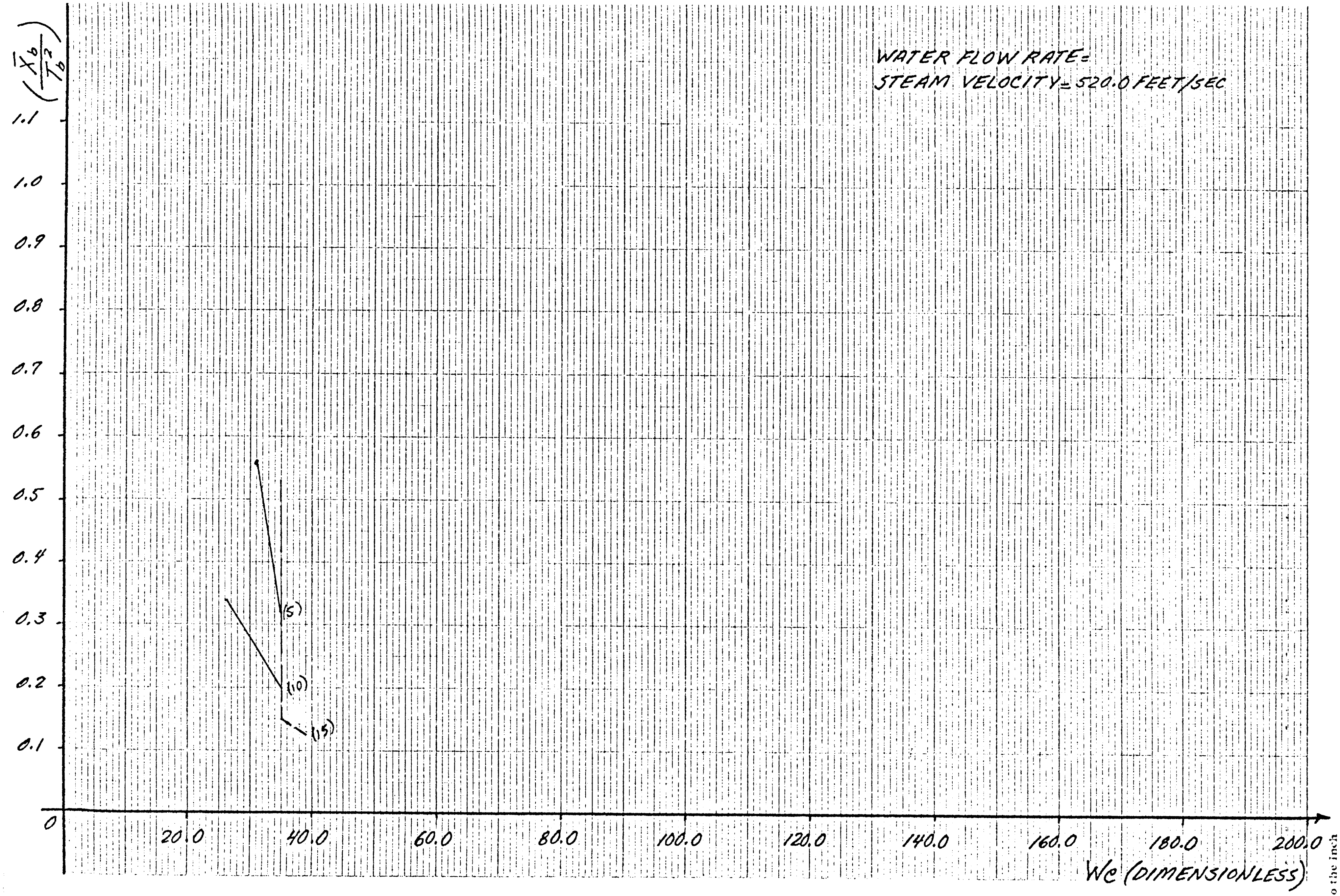

WATER FLOW RATE=
STEAM VELOCITY= 520.0 FEET/SEC
(numbers in parenthesis indicate flow rates)
(15)
(10)
(5)
t_b (SEC)
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
P_2 (PSIA)

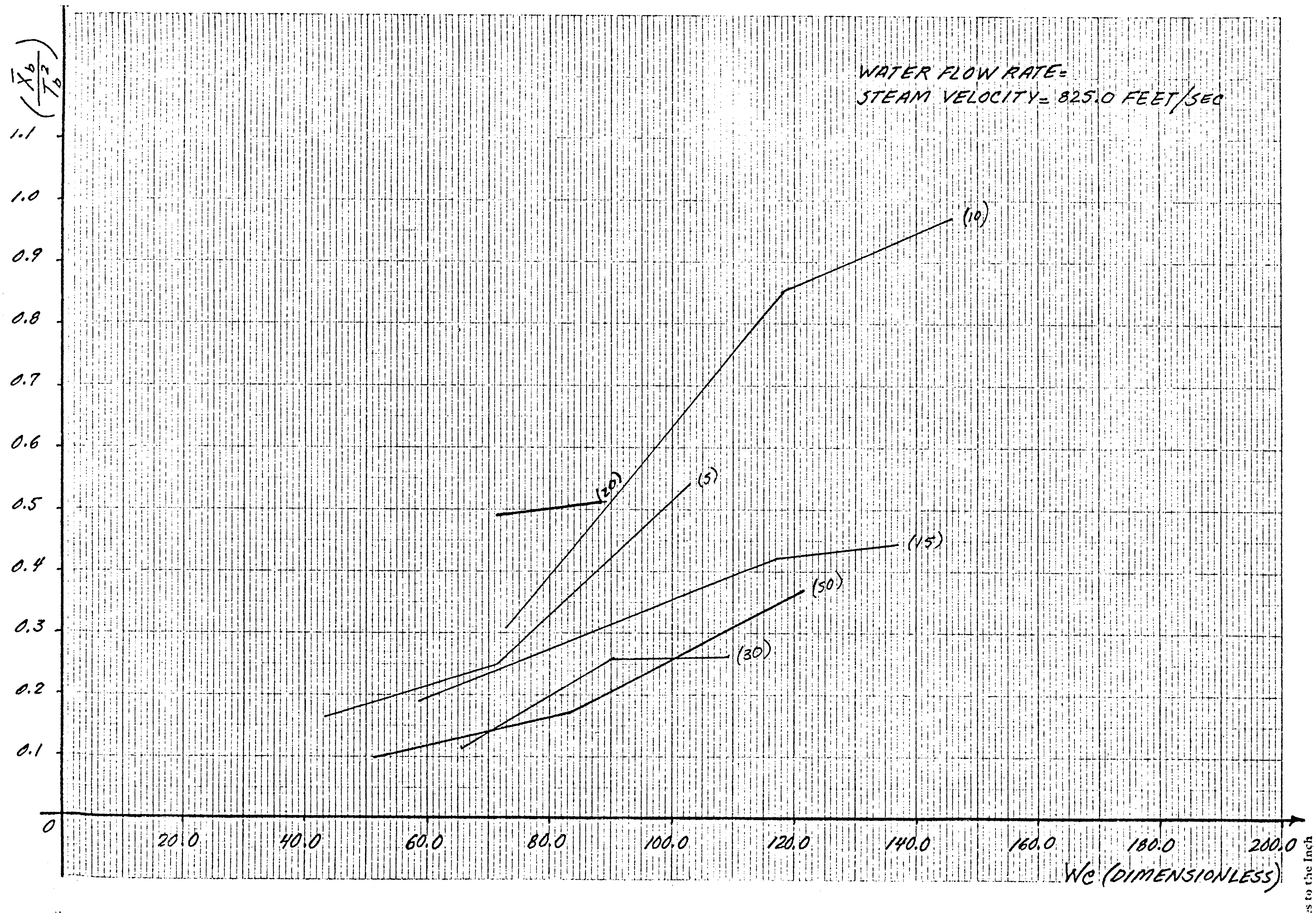

WATER FLOW RATE=
STEAM VELOCITY= 825.0 FEET/SEC
(numbers in paranthesis
indicate flow rates)
(50)
(30)
(6), (15)
(10), (20)
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
001
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
P_d (PSIA)

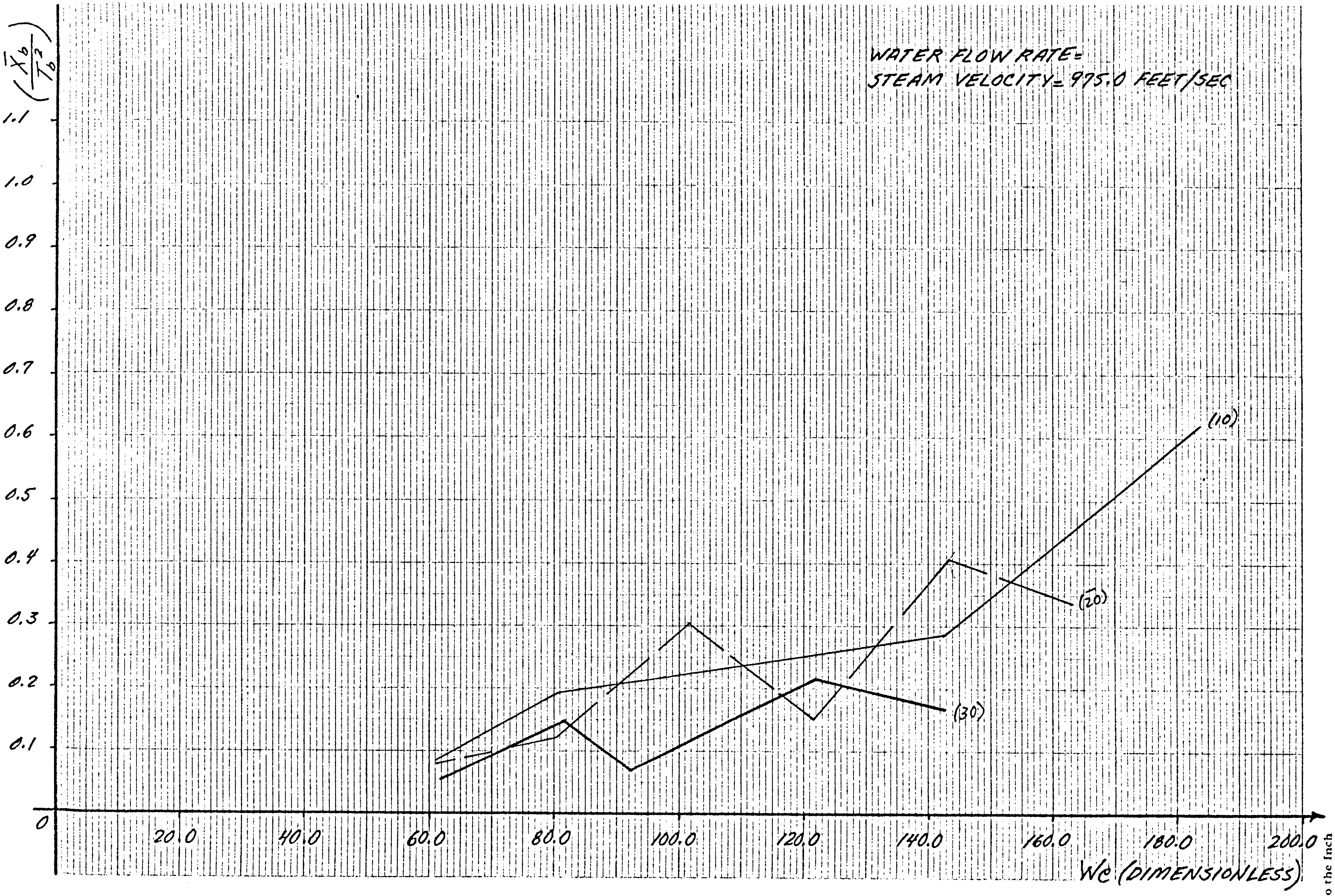

t_b (SEC)
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
P_2 (PSIA)
WATER FLOW RATE=
STEAM VELOCITY= 975.0 FEET/SEC
(20), (30)
(10), (15)

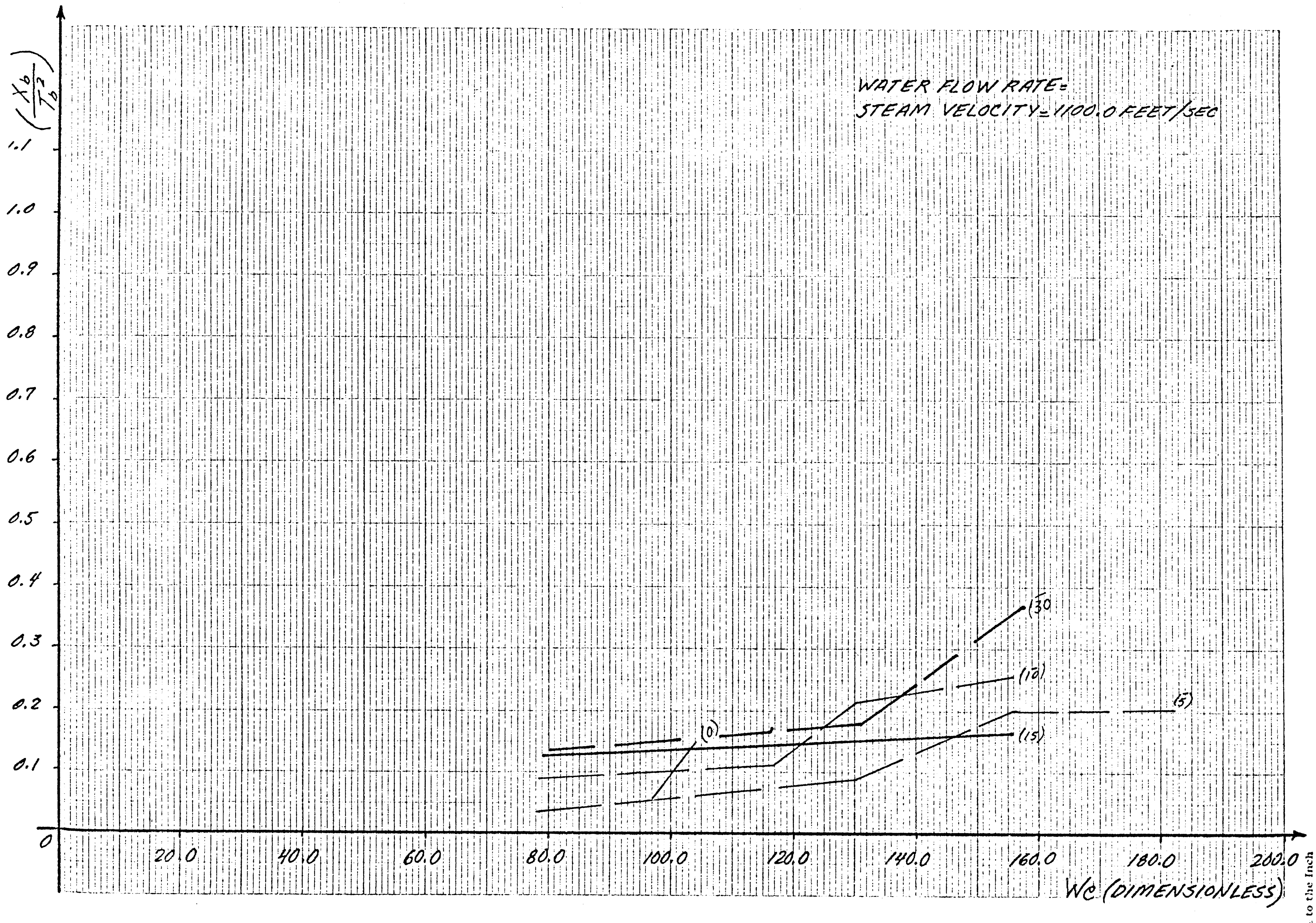

t_q
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
P_d (PSIA)
305 F/S
520 F/S
825.0 F/S
975 F/S
1100 F/S


WATER FLOW RATE=
STEAM VELOCITY= 305.0 FEET/SEC
$\left(\frac{\bar{X}_b}{T_b^2}\right)$
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Wc (DIMENSIONLESS)
(20)
(5)
(10)


WATER FLOW RATE=
STEAM VELOCITY=520.0 FEET/SEC
$\left(\frac{\bar{X}_b}{T_b^2}\right)$
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
We (DIMENSIONLESS)
(5)
(10)
(15)


WATER FLOW RATE=
STEAM VELOCITY= 825.0 FEET/SEC
$\left(\frac{\bar{X}_b}{T_b^2}\right)$
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
We (DIMENSIONLESS)
(10)
(20)
(5)
(15)
(50)
(30)


WATER FLOW RATE=
STEAM VELOCITY= 975.0 FEET/SEC
$\left(\frac{\bar{X}_b}{T_b^2}\right)$
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Wc (DIMENSIONLESS)
(10)
(20)
(30)


WATER FLOW RATE=
STEAM VELOCITY=1100.0 FEET/SEC
$\left(\frac{X_b}{T_b^2}\right)$
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Wc (DIMENSIONLESS)
(30
(10)
(5)
(15)
(0)