HEAT TRANSFER AND AGITATOR POWER REQUIREMENTS IN MECHANICALLY-AGITATED THERMAL PROCESSORS WITH FIXED-CLEARANCE AGITATORS

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HEAT TRANSFER AND AGITATOR POWER REQUIREMENTS

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WITH FIXED-CLEARANCE AGITATORS

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PREFACE

This dissertation is concerned with developing improved engineering design methods for thermal processors agitated by fixed-clearance agitators.

Experiments were conducted in a 4.058 inch inside diameter by 22 inch long heat exchanger. Heat transfer coefficients, agitator power requirements, and axial thermal diffusivity parameters were obtained experimentally and general correlations for each were obtained.

I am deeply grateful to my thesis adviser, Professor Kenneth J. Bell, first for being instrumental in allowing me to do graduate work in Chemical Engineering at Oklahoma State University, and second for giving technical and moral support during my Ph.D. program. I wish to thank the other members of my Advisory Committee, Professor R. N. Maddox, Professor J. H. Erbar and Professor J. A. Wiebelt, for their guidance during my studies here.

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CHAPTER I

INTRODUCTION

The industrial applications of mechanically-agitated fluid-processing equipment (MAFPE) are many and varied. The familiar unit operations of mixing, chemical reaction, heat transfer and mass transfer are frequently effected in such equipment. Here we shall be concerned only with those process design parameters which are necessary to design an agitated heat exchanger. These parameters are:

1. Agitator power requirement
2. Heat transfer coefficient
3. Mean temperature difference

There are many different types of MAFPE. This investigation is concerned with MAFPE which may be classified as "small-clearance." Typical "small-clearance" MAFPE are depicted schematically in Figure 1. "Small-clearance is used to describe the class of fluid processing equipment which employs agitators (anchors, scrapers, helical ribbons, extruders, etc.) that sweep practically the entire vessel volume. Thus not only is the clearance between the agitator and vessel "small" but also the agitator length is approximately equal to the vessel length. "Large-clearance" equipment employs agitators (propellers, turbines, paddles, etc.) that sweep only a small fraction of the vessel volume. For this latter class the clearance between agitator and the vessel wall is generally large and the agitator length is

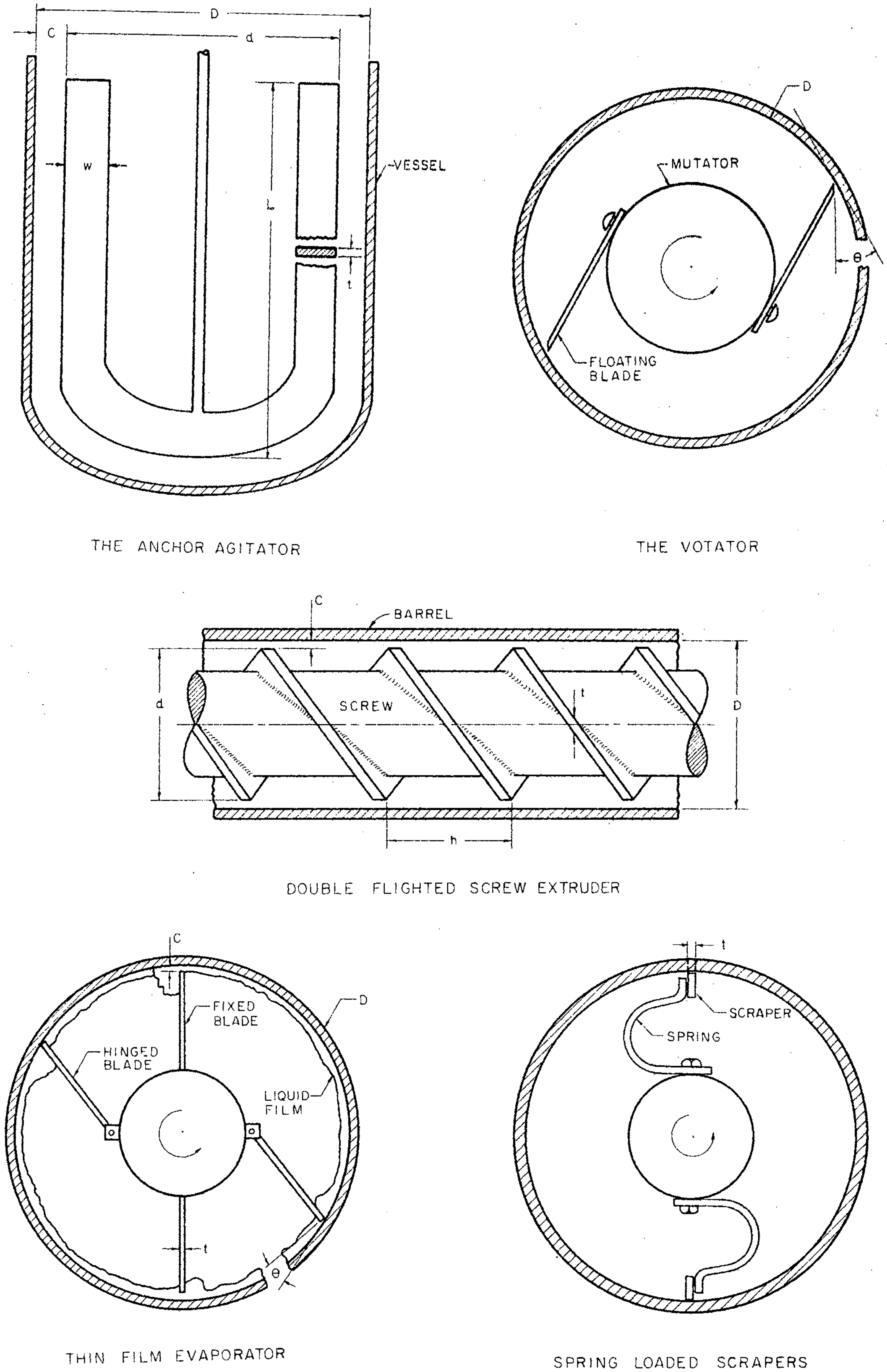


Figure 1. TYPICAL CLOSE-CLEARANCE EQUIPMENT.

small compared to the vessel length.

Much of the equipment which is here called "small-clearance" has heretofore been called "scraped-surface." This term is really a misnomer as almost invariably a film of liquid does exist between the agitator and vessel wall. "Scraped-surface" will only be used here to indicate the condition when the vessel wall is scraped clean.

Small-clearance equipment employs a myriad of agitator configurations. From a predictive standpoint, it is convenient to classify these configurations as either fixed-clearance or variable-clearance. Fixed-clearance equipment employs rigid agitators. In variable-clearance equipment the agitators are forced toward the vessel wall by springs, centrifugal action, hydrodynamic action of the fluid on the agitator and/or by the fluid friction between the agitator tip and the vessel wall. The "slipper bearing effect" acts to hold the agitator off the wall; thus, in general, the clearance varies with operating conditions.

The reason for discussing all the widely different devices just mentioned under the single classification of "small-clearance" arises from the need to generalize design correlations. In many cases a design method developed for one small-clearance device can also be used to design other small-clearance equipment.

Objectives of this Investigation

The primary objective of this investigation was to develop methods for calculating agitator power requirements, heat transfer coefficients and mean temperature differences for Newtonian fluids in MAFPE in which the clearance is small and fixed. Only liquid-full systems are considered.

Other investigators have conducted research aimed at these same ends. They have not been very successful. One of the major reasons for their lack of success is that they, for the most part, have investigated a particular piece of industrial apparatus. Industrial equipment has two serious shortcomings as research equipment. Industrial equipment is generally not instrumented to measure the parameters necessary to obtain a design method from first principles, and usually there are so many variables which affect equipment performance that it is very difficult to isolate the effect of any particular variable.

A sounder approach would be to first determine with some certainty the effect of the most important variable or variables and then use this as a foundation for correlating the effect of variables peculiar to a particular industrial apparatus.

With this in mind we have chosen to restrict this investigation to study directly only three variables: (1) the clearance between the agitator and the vessel wall, (2) agitator speed, and (3) axial flow rate.

The geometry of the experimental apparatus was the simplest possible - a flat knife-edged blade rotating in a cylindrical vessel. The agitator to tube wall clearance could be changed by disassembling the apparatus and adjusting the arms of the blade.

Design methods developed for this simple geometry should be at least approximately extendable to the more geometrically complex industrial equipment.

CHAPTER II

LITERATURE SURVEY

In a recent publication (36), Penney and Bell have presented a general review and analysis of the literature on power requirements, heat transfer coefficients and mean temperature differences for fluid processing equipment employing small-clearance agitators. The most pertinent parts of this review will be included here along with subsequent work and work which they did not adequately cover. This investigation is concerned with liquid-full systems. The literature on thin-film systems will not be covered here.

Agitator Power Requirements

Excellent treatises on agitator power requirements in general have recently been published by Bates, Fondy, and Fenic in Chapter 3 of reference (46) and by Chapman and Holland in reference (12). They have summarized previous work on agitator power requirements. Penney and Bell (36) summarized and analyzed the work on power requirements for small-clearance agitators. These studies will not be reiterated in toto here. The emphasis here will be placed on correlating techniques which appear to be fundamentally sound. Non-Newtonian work and work with a vortexing free-liquid surface will not be considered here.

Early workers on agitator power requirements developed a fundamentally sound method of predicting the effect of fluid properties on agitator power consumption. Dimensional analysis or non-dimensionalization of the Navier-Stokes equation can be used to show for an incompressible, non-vortexing, Newtonian fluid that, given geometrical similarity, the conventional power number ($\frac{P_t g_c}{\rho N^3 d^5}$) depends only upon the rotational Reynolds number ($\frac{N d^2 \rho}{\mu}$). This simple relationship has been used quite successfully to correlate power for agitators in liquids. The form of this correlation gives us much insight into the fluid flow phenomena in an agitated vessel because changes in the nature of the fluid flow are manifested by changes in the form of this correlation. Let us discuss the form of this correlation -- for a fixed geometry -- as we go from very low Re to very high Re. Generally below Re = 30 the curve of P vs. Re is a straight line with a slope of -1; this relationship can be obtained for an incompressible, Newtonian fluid by neglecting the inertia terms in the Navier-Stokes equations. Creeping flow regime is the term commonly used to describe that range of Re where inertia forces are negligible. This terminology shall be used here.

In the range $30 < Re < 10{,}000$ the slope of P vs. Re gradually changes from a slope of -1 to zero. In this region both "viscous" and "inertia" forces affect the agitator power requirement. Generally above Re = 10,000 the curve of P vs. Re is essentially flat; thus, the agitator power requirement is independent of Re and, therefore, independent of fluid viscosity; so the agitator power requirement is dependent totally upon "inertia" forces.

Obviously from the description above the fluid flow phenomena in an agitated vessel are analogous to those for fluid flow in a rough pipe with the friction factor replaced by the power number. However, there is one very important difference: In a pipe the inception of turbulence is responsible for a rapid increase in the friction factor as Re is increased; whereas, in an agitated vessel P changes very gradually as the fluid flow becomes turbulent. In fact, P changes so gradually that it is not possible to get even a rough estimate of where turbulence starts. As far as heat transfer and backmixing are concerned it is very important to know and describe quantitatively the conditions under which turbulence starts and where the last vestiges of laminar motion cease. For later discussion it is desirable here to establish criteria for laminar and turbulent flow in terms of Re. Developing turbulence has a much greater effect on heat transfer in an agitated vessel than it has on the agitator power requirement; we may anticipate some of the heat transfer results of this investigation at this early stage in this work and use these results to establish criteria for the following fluid flow regimes: the laminar regime, the transition regime and the turbulent regime. We should note here that the criterion ($Re < 30$) for the creeping flow regime was established in the preceding paragraph.

If the reader will turn to the final correlation for heat transfer for this investigation given in Figures 18,19,20, and 21, we shall define these flow regimes. The ordinate of these graphs is proportional to the heat transfer coefficient. These correlations indicate that turbulence, which has a significant effect on the heat transfer, starts about $Re = 150$. The effect of developing turbulence, especially for the small diameter blades, causes the heat transfer to increase rapidly with increasing Re up to about $Re = 700$ where there is a rather sharp break in the curve. Above $Re = 700$ the slope of the heat transfer correlation becomes essentially constant indicating that the random fluctuations of turbulent flow overshadow any remaining traces of periodic laminar motion. Based upon these observations, we shall use here the following criteria for the various flow regimes: creeping flow regime: Re < 30; laminar regime: Re < 150; transition regime: 150 < Re < 700; and turbulent regime: Re > 700.

The following investigators have used the fundamentally sound technique of plotting log P vs. log Re for a particular agitator geometry for correlating power requirements of small-clearance agitators: Uhl and Voznick (48) for anchors; Nagata et al. (34) for anchors, paddles, helical ribbons and augers; and Hoogendoorn and den Hartog (20) and Gray (18) for helical ribbons and augers. These correlations are only correct if complete geometrical similarity is retained from the experimental apparatus to the designed apparatus. Certain geometrical parameters may have very little effect on power but direct experimental evidence must exist before a geometrical variable can be neglected.

Other investigators have not been content to let geometrical variables be handled as parameters on a graph of log P vs. log Re. They have attempted to empirically correlate their effect by regression analysis and curve-fitting. The following investigators have used this approach: Foresti and Liu (17), Calderbank and Moo-Young (10) and Beckner and Smith (1) on anchors; Chapman and Holland (11) on augers; and Bourne and Butler (8) on helical ribbons.

Several of the references listed in the two preceding paragraphs are not sufficiently pertinent to this investigation to be covered in more detail here. In general the references which will be covered in more detail are those concerned with all work on anchor agitators and the theoretical work on screw extruders. Anchor agitators are the only agitators previously tested which are sufficiently akin, geometrically, to the flat blade tested here so that data taken with them can be meaningfully compared with data for the flat blade. The theoretical work on screw extruders is pertinent here because it will be helpful in developing correlating techniques.

Foresti and Liu (17) have attempted to correlate the agitator power requirements for a particular anchor agitator (i.e. the agitator geometry was fixed and only fluid properties were varied) by plotting the conventional power number (P) vs. a rotational Reynolds number which included ratios of geometrical parameters. This method is first of all unnecessary because it has already been pointed out that for a fixed geometry a plot of P vs. Re will correlate the data, and in the second place it is unsound because a Reynolds number should be based upon a single characteristic length.

Uhl and Voznick (48) conducted tests with anchor agitators in a 10 inch and a 24 inch diameter vessel. The four agitators tested in the 10 inch diameter vessel were not geometrically similar with the three agitators tested in the 24 inch diamter vessel. Two geometrical parameters were varied: the clearance between the agitator tip and the vessel wall (C) and the width of the anchor vertical arsms (w_a). The variation of w_a had a negligible effect on the agitator power consumption. Correlations of log P vs. log Re with C/D as a parameter were obtained for each vessel diamter. The data for the 10 inch diameter vessel did not coincide with the data for the 24 inch diameter vessel, but Uhl and Voznick noted that the data could be made to coincide if P were multiplied by the ratio of D to the "effective peripheral length" (EPL = L + D/4) of the agitator. They did not, however, recorrelate the data using this suggestion. The data for the 10 inch diameter vessel are almost entirely in the creeping flow regime, but the data for the 24 inch diameter vessel extend well into the transition regime (to Re = 2,000). The data for both vessels show that C has a pronounced effect on the agitator power requirement in the creeping flow regime; however, the data for the 24 inch diameter vessel indicate that C has a much less pronounced effect on the agitator power requirement in the mid-transition regime because these data for all three clearances almost coincide on the plot of log P vs. log Re near Re = 2,000.

Calderbank and Moo-Young (10) have used data of Uhl and Voznick (48) and Foresti and Liu (17) with their own data to develop a general correlating method (including non-Newtonian behavior and all geometrical variables) for anchor agitators. Only the Newtonian case will be considered here. A very important correction to this paper appeared in a later volume of the journal in which it was published; the reference to this correction is given in (10) here and Bates et al. (46) give the correction. Their corrected method for the Newtonian case has a power number (P') given in equation 2-1 below, which is only a function of the rotational Reynolds number.

$$P' = P\left(\frac{D_e'}{L_e'}\right)(n\,n_s)^{-2/3}\left(\frac{D}{2C}\right)^{1/2} \qquad (2\text{-}1)$$

where

n = number of blades or arms on the agitator, 2 for an anchor.

n_s = number of effective blade edges on the agitator, 2 for an anchor.

$\frac{L'_e}{D'_e} = 4(\frac{L_e}{D_e}) + 1/n_s$ = the equivalent vertical arm height to diameter ratio.

$D_e = D - w_a$

$L_e = L - w_c$

w_a = width of side-arm on the agitator.

w_c = width of the bottom crossmember on an anchor agitator.

The Newtonian data are correlated very well by this correlating method for wide range of Re ($0.2 < Re < 4,000$). However, there is a question about the validity of including geometrical ratios raised to powers in the power number. The data of Uhl and Voznick (48) indicate that C has a different effect on the agitator power requirement in the creeping flow regime than in the transition regime; if this be the case, then C raised to a constant power would not represent the data in both the creeping flow regime and in the transition regime. Bates et al. (46) have the following to say about this practice: "In correlating variations in geometry, many investigators have included geometry effects as simple factors directly in the power number expression. This can be done as a matter of convenience, but there is no theoretical reason for doing so, and the practice has many possibilities for error." They continue to explain that the most important reason this practice is not sound is that a geometrical parameter may not have the same effect in different flow regimes.

Also the correlating method of Calderbank and Moo-Young (10) does not include the thickness of the anchor side arm (t) as a correlating parameter. As $C \rightarrow 0$ the thickness of the anchor side arm would be expected to have a very pronounced effect on the agitator power requirement.

Beckner and Smith (1) have taken anchor agitator power data in a 22.9 centimeter diameter vessel with both Newtonian and non-Newtonian fluids. Only the Newtonian case will be considered here. Several anchors of different diameters were tested. The data were correlated on a plot of log P vs. log Re with C/D as a parameter. All data were in the creeping flow regime; therefore, for each clearance a separate straight-line curve of slope of approximately -1 resulted. The data were curve-fitted with the following equation:

$$P\left(\frac{C}{D}\right)^{1/4} = \frac{82}{Re^{0.93}} \qquad (2\text{-}2)$$

One could define a new power number $P' = P(C/D)^{\frac{1}{4}}$ from this relationship; therefore, the previous comments about the validity of including geometrical ratios raised to constant powers in the power number would apply to the above equation. This correlating method also does not include the anchor side arm thickness as a correlating parameter, nor, in fact does it include the length of the agitator (L), which Calderbank and Moo-Young's (10) correlation indicates has a pronounced effect on the agitator power requirement.

Penney and Bell (36) have proposed a new correlating method which considers all geometrical variables and in particular it includes the effect of the agitator thickness (t). This method draws heavily from previous theoretical work on screw extruders which is well summarized by Squires (3, 42) and Booy (7).

The power requirements of the extruder screw are assumed to be the sum of three processes, which are separately analyzed:

1. Power consumed between the flight edge and the extruder barrel (called <u>clearance effects</u> hereafter in this paper).

2. Power dissipated by viscous shear in the screw channel (called bulk effects hereafter).

3. Power required to raise the fluid pressure.

Only clearance and bulk effects will be considered here since the third effect is usually not present to any appreciable extent in other small-clearance equipment where the agitator does not function as a pump.

The clearance effects are calculated assuming the clearance is so small that the barrel and flight edge approximate two flat plates. One plate of width L and infinite in length is assumed stationary; the other plate of width L and length t is assumed to move parallel to the infinitely long plate with a velocity equal to the peripheral velocity of the agitator tip: $\pi \times d \times N$. End effects are neglected and the fluid motion is assumed laminar. The gap between the plates is assumed to be filled with a Newtonian fluid of viscosity μ. Using the familiar Newtonian expression relating shear stress in the fluid to the velocity gradient in the fluid the following expression for the power dissipation in the clearance is obtained for a two-blade agitator.

$$P_c = 2\pi d^2 N^2 \left(\frac{\mu}{g_c}\right)\left(\frac{t}{C}\right) L \qquad (2\text{-}3)$$

Booy (7) has done the most recent work on predicting the bulk power dissipation. He has considered screw channel curvature, whereas previous investigators had approximated the curved channel with a straight channel. He assumed that the channel depth is small compared to the width. Mohr and Mallouk (3) have obtained a solution which takes into account the effect of the clearance on the channel power. Although all these solutions are approximate, they do give the pertinent dimensionless parameters and suggest the correct functional form of correlation. These solutions result in the following relationship for bulk power:

$$P_b = 4\pi^3 d^2 N^2 \left(\frac{\mu}{g_c}\right)\left[f\left(C/d,\ d_s/d,\ h/d\right)\right]L \qquad (2\text{-}4)$$

Penney and Bell (36) have put these relationships in the following dimensionless forms:

$$P_{cL} = \frac{2\pi^2}{Re}\left(t/c\right) \qquad \text{for clearance power} \qquad (2\text{-}5)$$

$$P_{bL} = \frac{\beta}{Re} f\left(C/d,\ d_s/d,\ h/d\right) \qquad \text{for bulk power} \qquad (2\text{-}6)$$

These relationships contain a new power number which includes d^4L rather than d^5. These relationships were developed by neglecting inertia forces; it shall be shown in Chapter 5 that they also hold for turbulent flow. This has very important consequences. This power number correlates the effect of agitator length in all flow regimes. Thus geometrical ratios involving the agitator length are eliminated from consideration.

Penney and Bell (36) have recorrelated data for anchors, ribbons and augers. They calculated that the clearance power is for all practical purposes negligible for data in the literature. Thus, the power is not a function of the agitator thickness (t). The data of Uhl and Voznick (48) indicate that agitator arm width for commonly used anchors has little effect on the agitator power requirement. With this knowledge a plot of P_{tL} vs. Re with C/D as a parameter correlates the data of anchor agitators. For ribbons and augers in addition to C/D there are three other geometrical parameters which must be considered: h/C, d_s/D and w_r/D. For agitators in common use Penney and

Bell (36) expect d_s/D and w_r/D will have less effect than C/D on the agitator power requirement. They plot P_{tL} vs. Re with C/D and h/D as parameters. This correlating method is fundamentally sound.

Bulk and clearance power requirements have not been shown experimentally to be independent. Also no investigator has even taken experimental data which could be classified as either bulk power only or clearance power only.

Heat Transfer Coefficients

Uhl in Chapter 5 of reference (46) and Chapman and Holland in reference (12) have presented summaries of all work on heat transfer in agitated fluid processing equipment. Penney and Bell (36) have recently summarized and analyzed the work on heat transfer in small-clearance equipment.

Huggins (21) was probably the first researcher to publish data demonstrating that scrapers were effective in improving heat transfer from a vessel wall to a viscous liquid but not very effective for thin liquids. Laughlin (28) also presented early data on heat transfer in a "scraped-surface" vessel.

Brown, Scott and Toyne (9) conducted plant tests in the turbulent regime on two anchor agitators (1 inch and 5 inch clearance between the outer edge of the anchor and the vessel wall) in a 5-foot diameter pot-type vessel. At 40 r.p.m. the 5 inch clearance anchor gave about 20 percent higher heat transfer coefficient than the 1 inch clearance anchor. For practical correlating purposes only viscosity was varied; however, by taking the exponent on Re from a previous work on paddles by Chilton, Drew and Jebens (13), they proposed the following correlation:

$$\frac{Nu}{Pr^{1/3}} \phi^{0.14} = 0.36 \ Re^{2/3} \tag{2-7}$$

Uhl (47) and Uhl and Voznick (48) have conducted tests on anchors (10 inch and 24 inch diameter vessels) in the transition regime. The data are correlated on a log-log plot of $\frac{Nu}{Pr^{1/3}} \phi^{0.18}$ vs. Re. The following relationships represent the data;

$$Nu = 1.34 \ Re^{0.44} Pr^{1/3} \phi^{0.18} \ [Re < 400] \tag{2-8}$$

$$Nu = 0.27 \ Re^{0.7} Pr^{1/3} \phi^{0.18} \ [Re > 400] \tag{2-9}$$

The data are more scattered for Re$<$400 than for Re$>$400. An interesting phenomenon was discovered which did not appear in the final correlation: An intermediate clearance gave the highest heat transfer coefficients.

Kapustin (24) has conducted tests with an anchor agitator in the laminar regime. The suggested correlation is;

$$Nu = 1.38 \ Re^{1/2} Pr^{0.28} \tag{2-10}$$

Considerable research effort has been directed toward developing design methods for the Votator. Houlton (22) in 1940 cooled hot water in a Votator and published his data. Bolanowski and Lineberry (6) in 1952 conducted tests on a number of food products.

From 1958 to 1962 Skelland and co-workers (38,39,40) conducted a lengthy investigation aimed at developing a general design method for the Votator. Their work culminated with the following correlation;

$$\frac{hD}{k} = \alpha \left(\frac{C\mu}{k}\right)^{\beta} \left(\frac{(D - D_s) v \rho}{\mu}\right)^{1.0} \left(\frac{DN}{v}\right)^{0.62} \left(\frac{D_s}{D}\right)^{0.55} (n_B)^{0.53} \tag{2-11}$$

For cooling viscous liquids $\alpha = 0.014$ and $\beta = 0.96$; for cooling thin mobile liquids $\alpha = 0.039$ and $\beta = 0.70$. No criterion is given for "viscous." The functional dependence of h on the parameters of the correlation is as follows:

$$h \propto \frac{(D-D_s)^{1.0} D_s^{0.55} \upsilon^{0.38} N^{0.62} n_B^{0.53} k^{1-\beta} \rho^{1.0} c^{\beta}}{D^{0.93} \mu^{1-\beta}} \qquad (2\text{-}12)$$

Penney and Bell (36) have pointed out that this relationship is only applicable for the range of experimental data because h should not approach zero as D, $(D-D_s)$ and υ approach zero and that it is most unlikely that $h \propto k^{0.04}$ in the viscous regime. They also point out that the dependence on axial flow velocity predicted by equation (2-11) probably arose because backmixing was ignored when the data were reduced. Axial flow only affected the heat transfer coefficient indirectly through its effect on the mean temperature difference (MTD).

Uhl (46) has recently recorrelated the Votator data of Houlton (22) and Skelland (40) and the data of Huggins (21) for scraping and non-scraping counterrotating sweep and paddle agitator by plotting $\frac{Nu}{Pr^{1/3}} \phi^{0.18}$ vs. Re. The data are correlated better in the turbulent regime (Re > 400) than in the laminar regime (Re < 400). The data indicate that the clearance between the agitator edge and the vessel wall has a considerable effect on the heat transfer coefficient in the laminar regime but has little effect in the turbulent regime.

Kool (26), Harriott (19) and Latinen (27) have suggested that the penetration theory should be applicable to the prediction of heat transfer coefficients in the Votator and similar "scraped-surface" equipment. The heat transfer coefficient from the penetration theory is as follows:

$$h = 2\sqrt{\frac{k\rho c}{\pi \theta}} \tag{2-13}$$

Latinen (27) has put this relation in the following dimensionless form for a two-bladed agitator:

$$Nu = 1.6\sqrt{Re\,Pr} \tag{2-14}$$

Latinen (27) checked the penetration theory with the data of Houlton (22) and Skelland (38). The data of Houlton checked well but those of Skelland did not. The data of Houlton were in the turbulent regime ($Re > 700$) and those of Skelland in the transition regime ($150 < Re < 700$). Latinen concluded that the heat transfer mechanism in the transition regime must be very different from that implied by assumptions of the penetration theory. The effects of axial dispersion undoubtly confounded the check of Skelland's data. Harriott (19) took data on carrot puree and oil in a Votator and checked these data, along with Houlton's (22) data, with the penetration theory. The penetration theory predicted coefficients up to 50 percent too high for the puree and oil. Harriott (19) suggested that the penetration theory may have predicted high coefficients because the viscous fluids did not return to the heat transfer at their bulk temperature.

Penney and Bell (36) have noted that the penetration theory only agrees with experimental data for the Votator in the turbulent regime, but they go on to point out that the penetration theory predicts that the heat transfer coefficient is independent of fluid viscosity (which it is in the creeping flow regime); whereas, it is known from many previous experiments that the heat transfer coefficient is significantly dependent upon fluid viscosity in the turbulent regime. They thus conclude that the penetration theory is not applicable to the prediction of heat transfer coefficients in agitated heat exchangers.

The Votator blades do not wipe the wall of fluid. The hydrodynamic lift force keeps the blade off the wall resulting in a residual liquid film after the wiper passes. This residual film would be expected to affect heat transfer. Kool (26) and Jepson (23) have suggested that this film might be considered for predictive purposes as a solid layer on the exchanger wall. They both show graphically how a stagnant film of liquid would affect the heat transfer coefficient predicted by the penetration theory. Bell (2) noted that the stagnant film-penetration theory model could be approximately expressed in closed form as

$$h = \frac{1}{C/k + \frac{1}{\sqrt{\frac{8C\rho kN}{\pi}}}} \qquad (2\text{-}15)$$

This relationship can also be expressed in the following dimensionless form:

$$Nu = \frac{1}{C/D + \frac{1}{1.6\sqrt{Re\,Pr}}} \qquad (2\text{-}16)$$

Penney (37) has checked this model with laminar flow data from a constant clearance device called the Spiralator. For large clearances, theory and experiment agreed well but for clearances approaching zero this model predicted coefficients 100 percent too high. This check is only qualitative because the effect of axial flow on the heat transfer coefficient could not be separated from the overall effect of axial flow plus agitator rotation. Clearly this model is in error for small clearance because the axial flow would, if anything, increase the coefficient above that existing at zero flow.

From a practical design standpoint, the correlation of Uhl and Voznick (48), which correlates $\frac{Nu}{Pr^{1/3}}\phi^{0.18}$ vs. Re, is the only design method which one could use with any degree of confidence. In the turbulent regime this method is probably adequate to predict the heat transfer coefficient but in the laminar regime there appears to be an effect of clearance which has not yet been determined.

The Effect of Axial Dispersion of Heat on the Mean Temperature Difference

Before examining specific literature it seems worthwhile to make some general comments concerning the effect of axial dispersion of heat on the mean temperature difference in heat exchangers. In an agitated heat exchanger there arethree possible mechanisms for the axial dispersion of heat:

1. axial molecular conduction in the fluid stream
2. axial conduction in the conduit wall and agitator
3. "backmixing", i.e., convective transport of heat which tends to level out the axial temperature, (e.g. Taylor vortices and fully developed turbulence).

Effects (1) and (2) have not been investigated, but there is a voluminous literature pertaining to backmixing. Much of it is only of marginal concern to this investigation, and only that most pertinent to this investigation will be covered here. Recent review articles by Li (30), Bischoff (4), Klinkenberg (25) and Oldshue (35) have covered the general field.

There are really three rather distinct problems associated with developing a design method for the effect of backmixing on the mean

mean temperature difference (MTD). The <u>first</u> problem is to develop a mathematical model for the backmixing phenomenon. The <u>second</u> problem is to develop experimental techniques to measure the backmixing parameters of the mathematical model. The <u>third</u> problem is to correlate the backmixing parameters with the operating parameters of the heat exchanger.

Historically there have been two approaches to developing mathematical models for backmixing - the "dispersion model" and the "equivalent completely mixed stage" concept which has been advanced by Young (50) and others. The dispersion model is equivalent to Fick's law of diffusion or Fourier's law of heat transfer with the molecular transport coefficient replaced by an effective transport coefficient (α_E) due to the backmixing. Thus the dispersion model is a one parameter model, namely (α_E). The "equivalent completely mixed stage" concept views the backmixing in terms of the number of completely mixed stages which will give the same performance as the real process; it has not proven very useful because it has not been possible to obtain general correlations of the equivalent number of stages in terms of the operating parameters. Only the dispersion model will be discussed further.

The first solution of the dispersion model of interest here was given by Danckwerts (15) in 1953. He solved for the effect of backmixing on a first order chemical reaction in a tubular reactor with no axial dispersion in the inlet and outlet lines. Wehner and Wilhelm (49) have generalized Danckwerts' solution to include dispersion in the inlet and outlet lines. Their theoretical results predict that dispersion in the inlet and outlet lines does not change the theoretical solution for the reactor. These solutions are exactly the same as the solutions for the fluid temperature distribution in a heat exchanger with constant wall temperature. They are recast in heat transfer terms in Appendix A for sake of completeness here. The final solution for fluid temperature vs. axial distance in the heat exchanger is given below:

$$\frac{T-T_w}{T_i-T_w} = g\, e^{\frac{Pe\,Y}{2}}\left[(1+a)\, e^{\frac{Pe}{2}(1-Y)} - (1-a)\, e^{-\frac{Pe}{2}(1-Y)}\right] \tag{2-17}$$

$$g = \frac{2}{(1+a)^2 e^{\frac{a\,Pe}{2}} - (1-a)^2 e^{-\frac{a\,Pe}{2}}} \tag{2-18}$$

$$a = \sqrt{1 + 4\beta/Pe} \tag{2-19}$$

$$\beta = \frac{hA}{Wc} \tag{2-20}$$

$$Pe = \frac{UL}{\alpha_E} \tag{2-21}$$

Note that the temperature at any location is a function of only two dimensionless parameters: β and Pe. The solution above is also applicable to extraction when the concentration in one phase can be assumed constant. For two parallel flow streams in intimate contact and transferring heat or mass, the solution to the dispersion model is given by Sleicher (41), Miyauchi (33) and Miyauchi and Vermeulen (32). As far as this investigation is concerned, the above papers have solved the first problem mentioned above, namely, developing a mathematical model for the backmixing phenomenon.

Miyauchi and Vermeulen (32) also shed some light on the second problem of developing experimental techniques to determine the dispersion parameters (for our case Pe). For the case of constant wall temperature they have shown that only the temperature jump ratio $\left(\frac{T_0 - T_i}{T_L - T_i}\right)$ and β have to be measured in order to determine Pe. The relationship between $\frac{T_0 - T_i}{T_L - T_i}$, β and Pe is derived from the appropriate solutions to the dispersion model in Appendix A:

$$\frac{T_0 - T_i}{T_L - T_i} = \frac{g\left[(1+a)\,e^{a\frac{Pe}{2}} - (1-a)\,e^{-a\frac{Pe}{2}}\right] - 1}{2ag\,e^{Pe/2} - 1} \qquad (2\text{-}22)$$

Pe can be determined from steady-state tests using this equation. The temperature just inside the inlet line of the exchanger (T_0) is the only experimental measurement which has to be made over and above those normally taken in heat transfer experiments.

A much more widely used technique to determine the dispersion parameter is the use of tracer tests. In this transient method some property of the inlet stream is varied and the response of the outlet stream to this variation is measured. There are three common methods of pulsing the input stream:

1. A step change is made to some property.
2. A delta-function change is made to some property.
3. A sinusoidal change is made to some property.

The response of the outlet stream to these changes can be determined analytically from the dispersion model. The dispersion parameter is determined from experimental data by determining the best fit of the theoretical solution to the experimental response. Levenspiel (29) and Bischoff and McCracken (4) have discussed methods of determining Pe from tracer tests.

There are two recent references in which axial dispersion was measured with are pertinent to this investigation. Mixon, Whitaker and Orcutt (31) have used the transient delta-function pulse input method (with a radioactive tracer) to measure $\mathcal{D}_E$ in a liquid-liquid spray tower heat exchanger (water as the continuous phase and a light oil as the discontinuous phase). They also analyzed earlier oil-water spray tower data and obtained α_E from measurements which were taken using both the steady state method and the transient method. For equivalent operating conditions α_E (obtained from both steady state and transient tests) and $\mathcal{D}_E$ were found to be approximately equal.

Croockewit, Honig and Kramers (14) have measured the effective diffusivity of mass in an annulus with the inner cylinder rotating by measuring the response of a sinusoidal tracer input. They have obtained a correlation for in terms of the system parameters. This correlation and the conclusions to be drawn from it will be discussed in the next paragraph. Their mechanical system differed from the system used here only in the agitator. This is the only system found in the literature which might be expected to obey the same general correlation as the system of this investigation.

Now we move to the third and last problem mentioned previously, namely, correlating backmixing with the operating parameters of the system. Taylor (43,44) was the first investigator to tackle this problem theoretically. He solved the axial dispersion problem for completely laminar and completely turbulent flow in tubes. He showed that the dimensionless dispersion parameter ($\frac{\alpha_E}{UL}$) was a function of Re and Sc (in fact $\frac{\alpha_E}{UL} \sim$ ReSc) in the laminar regime and a function only of Re in the turbulent regime. Levenspiel (29) presents these relationships in graphical form and shows the typical range of experimental data. Later investigators have for the most part used equivalent correlating methods. In general a dimensionless dispersion parameter is correlated as a function of the pertinent dimensionless fluid dynamical parameters of the system. For an agitated heat exchanger in the turbulent regime one would expect that the dispersion number might be correlated with the geometrical parameters, the rotational Reynolds number and the axial flow Reynolds number. Croockewit, Honig and Kramers (14) have done just this. For the annulus with the inner cylinder rotating they plotted $\frac{4\mathcal{D}_E}{N(D-d)d}$ vs. $\frac{N(D-d)d}{2\nu}$ and found that all data fell essentially on the same curve. Thus neither a change in axial flow rate (axial Reynolds number) or a change in inner cylinder diameter (geometry) affected the relationship between $\frac{4\mathcal{D}_E}{N(D-d)d}$ and $\frac{N(D-d)d}{2\nu}$.

Penney and Bell (36) have pointed out that there is no method to predict the effect of backmixing on the MTD in heat exchangers. In fact, no investigator of heat transfer in agitated heat exchangers, except a recent investigation by Uhl and Root (45) on heat transfer to agitated particulate solids, has even considered that backmixing could affect equipment performance. In some investigations, the effect of backmixing has been mistaken for the effect of axial flow rate.

CHAPTER III

DESCRIPTION OF EQUIPMENT

A photograph and a schematic diagram of the test apparatus are presented as Figures 2 and 3 respectively.

The apparatus is composed of the following major items:

1. The test heat exchanger
2. The A.C. auto transformer and the nichrome heating element
3. The D.C. motor which rotates the agitator
4. The test fluid reservoir
5. The test fluid circulating pump.

Test Heat Exchanger

Figure 4 is an assembly drawing of the test exchanger. The shell of the exchanger was a 4.058 inch inside diameter and 4.46 inch outside diameter aluminum cylinder. The ends of the exchanger were constructed from 3/4 inch thick Plexiglass sheet. The aluminum agitator was a flat knife-edged blade so designed that the clearance between the agitator blade tip and the exchanger shell wall could be varied.

The exchanger wall temperature was measured in eleven locations (2 inches apart and 1 inch from either end) with 30 gauge, teflon-coated, iron-constantan thermocouples. The thermocouple junctions were made with mercury bath thermocouple welder. The thermocouples were inserted into holes drilled almost tangentially into the exchanger wall

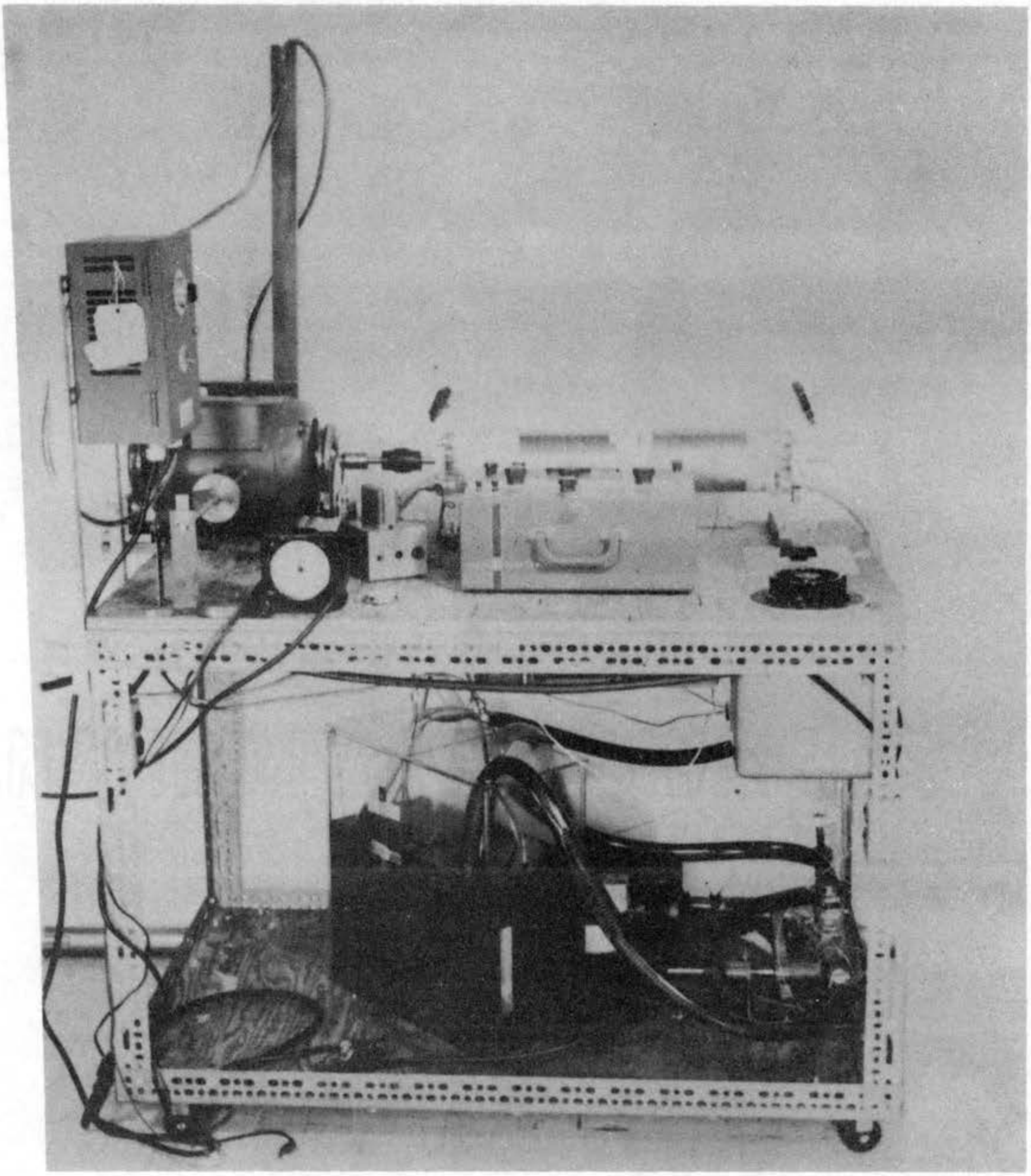


Figure 2. Photograph of Experimental Apparatus

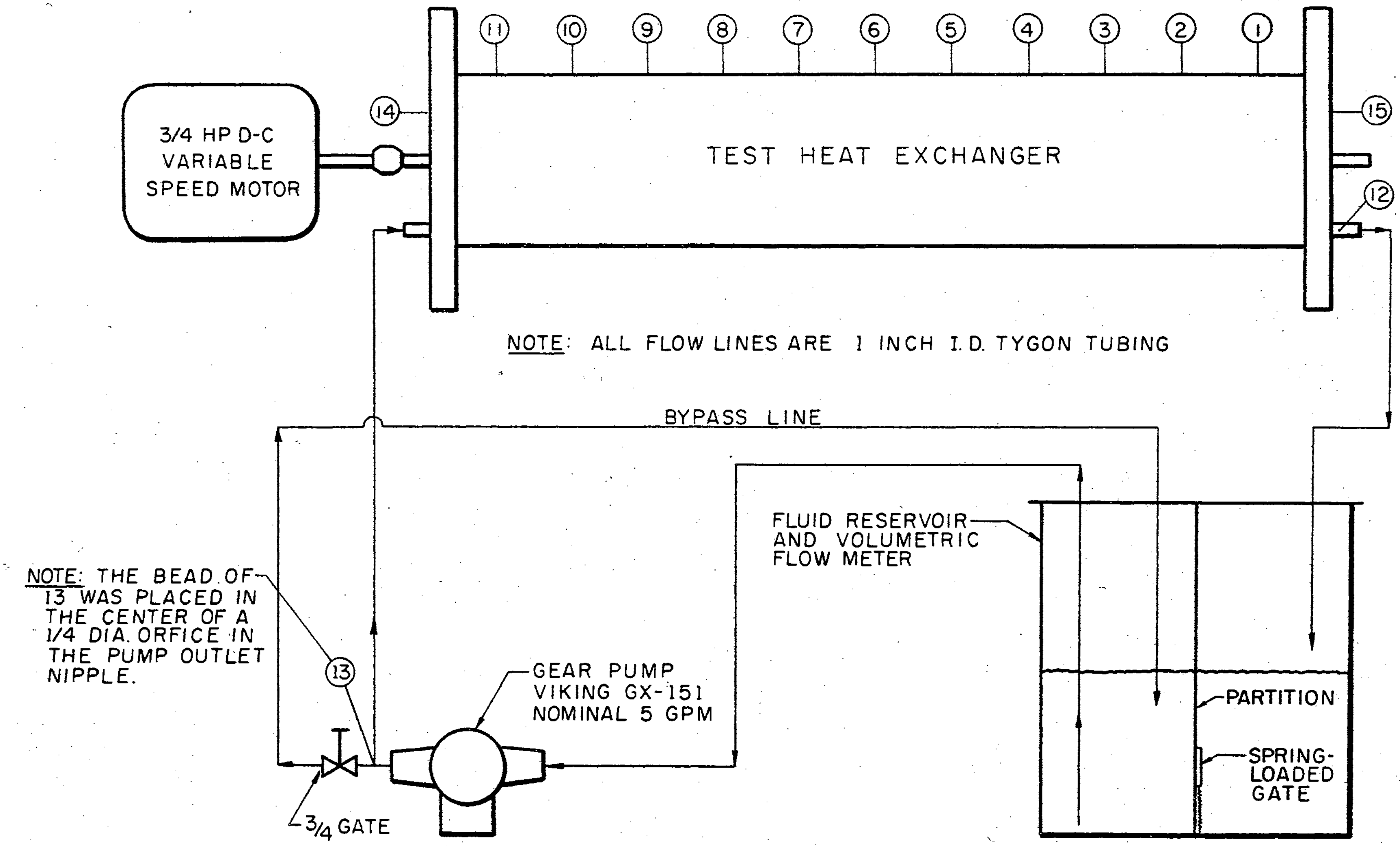


Figure 3. FLUID FLOW AND TEMPERATURE MEASUREMENT SCHEMATIC.

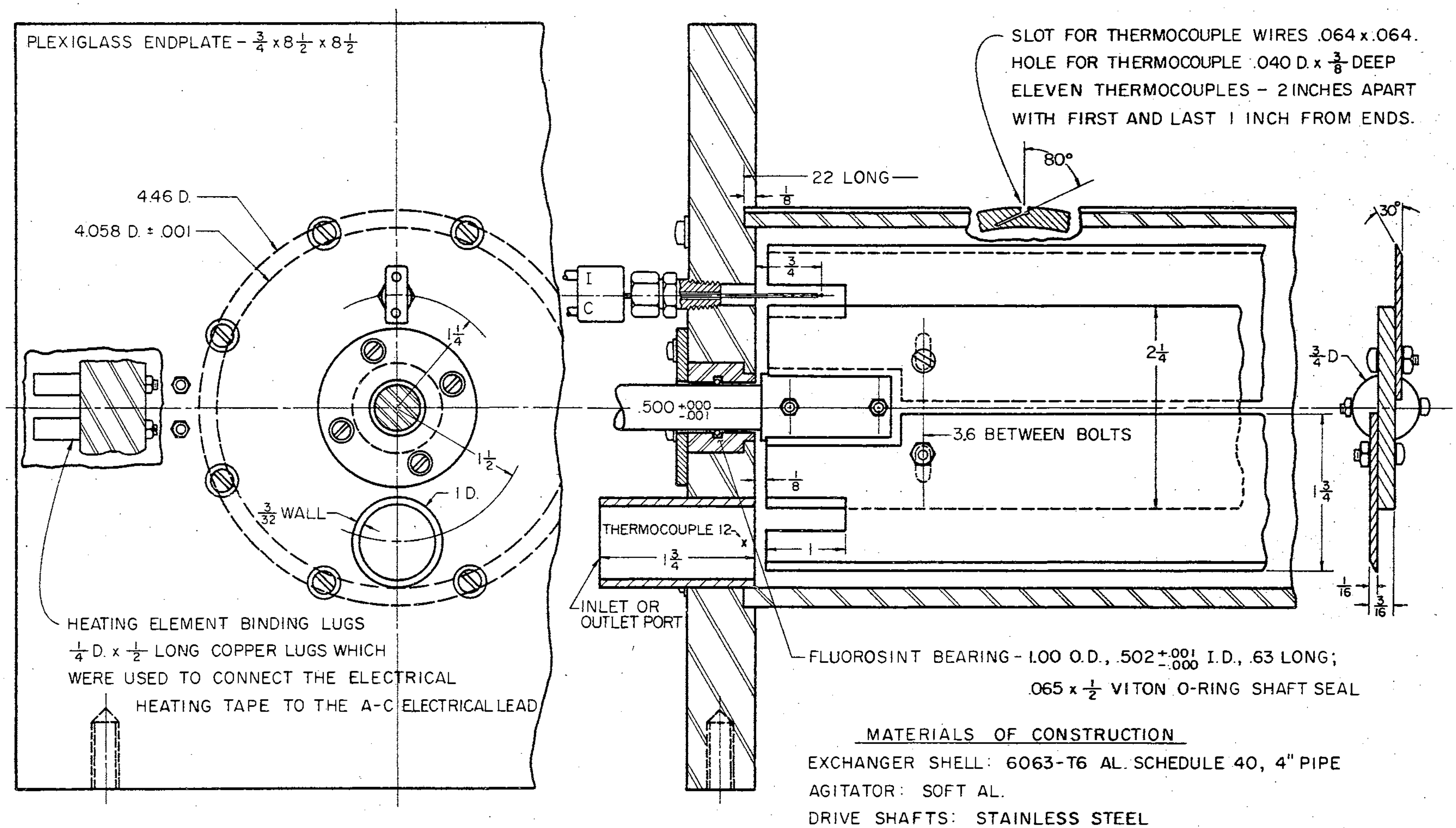


Figure 4. ASSEMBLY DRAWING OF THE TEST HEAT EXCHANGER.

as shown in Figure 4. The thermocouple leads were brought out in a groove in the exchanger wall. The leads were covered in the groove with a strip of sheet aluminum which was peened into the groove so that it was flush with the outside of the wall. The thermocouple junctions in the drilled holes were approximately 1/16 inch from the inside wall.

Thermocouples sheathed in stainless steel were inserted through the endplates in order to measure the temperature just inside the exchanger inlet and just inside the exchanger outlet. Slots in the agitator prevented these thermocouples from striking the rotating agitator.

The fluid temperature just outside the exchanger at the outlet was measured by inserting teflon-covered thermocouples into the exchanger outlet port. The thermocouple wires were led out between the Tygon outlet line and the Plexiglass port.

The shaft bearings were made of Fluorosint. Viton O-rings were used as shaft seals.

The exchanger was electrically heated over the entire length by Chromel A heating tape (0.002 inch thick, $\frac{1}{2}$ inch wide, 0.531 ohms per foot). The heating tape was wrapped over teflon-tape electrical insulation. The gap between successive windings of the tape was approximately 1/32 inch. The electrical power to the tape was supplied through a 220 volt, 20 ampere Powerstat.

Motor, Dynamometer and Tachometer

The agitator was driven by a 3/4 hp DC motor (manufactured by Century Electric). The motor speed was varied between 0-1200 rev./min.

by an ACF Electronics Model 430 Motor Control.

The motor was cradle-mounted as depicted in Figure 5 so that torque could be measured. The torque was measured by weights which were slid along an arm attached to the motor frame until the torque produced by the weight equaled the motor torque.

The motor speed was measured by timing an integral number of revolutions of an idler which was belt-driven from the motor-shaft. As the idler rotated it actuated a roller microswitch once per revolution. This switch in turn caused an electric counter to advance one digit per revolution. Timing was done with a standard Electric Time Co. electric timer (smallest graduation on face 1/100 second). The electric counter was connected to the timer switch so that the timer and counter were started and stopped simultaneously.

Pump and By-Pass Valve

The pump was a Viking GX-151 gear type (nominal 5 GPM). It was belt driven at approximately 400 rpm by a $\frac{1}{2}$ hp, 1725 rpm, A.C. motor. The flow rate through the exchanger was controlled with a 3/4 inch gate valve.

Reservoir, Flow Meter and Cooling Coils

The reservoir was constructed of $\frac{1}{4}$ inch thick Plexiglass sheet. It was partitioned along a vertical centerline into two 8 x 8 x 18 inch compartments. The pump suction line and the bypass line terminated in the other compartment. A spring-loaded, liquid-tight gate was built into the center partition. The volume flow rate of the liquid through the exchanger was obtained by closing this gate and

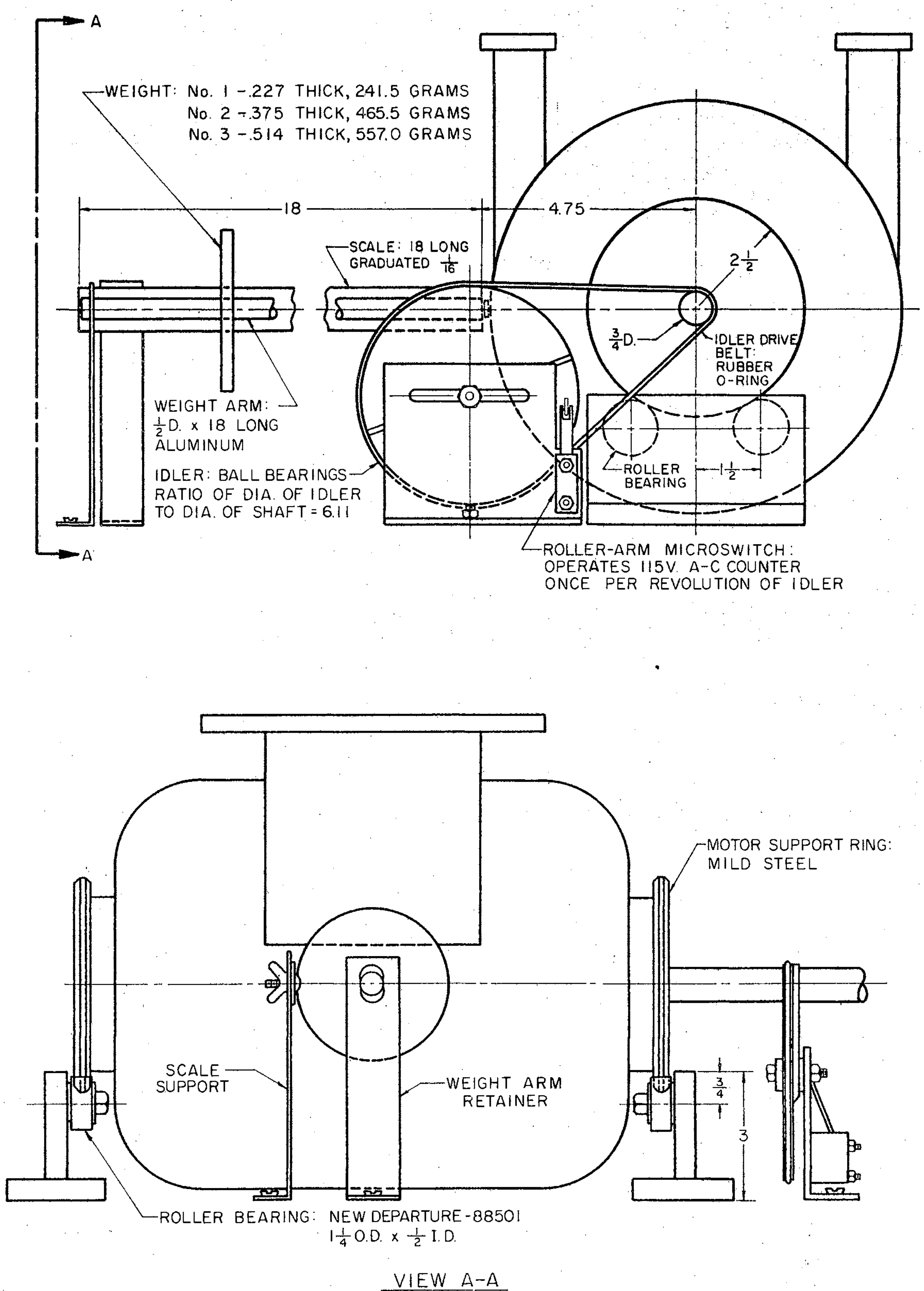


Figure 5. SCHEMATIC OF DYNANOMETER AND TACHOMETER

then measuring the time required for the liquid to rise a measured distance up the wall of the compartment in which the exchanger outlet line terminated.

Cooling coils were placed in both compartments of the reservoir. Each contained approximately 50 feet of $\frac{1}{4}$ inch copper tubing wound into two concentric coils of approximately 6 inches and 4 inches diameter. City water was used for cooling.

Electrical Power Measurements

The voltage drop across the electrical heating tape was measured with a Weston Model 433 A.C. voltmeter which has three scales: 0 to 150 volts, 0 to 300 volts, and 0 to 600 volts. The 0 to 150 volt scale was always used. The guaranteed accuracy was $\pm$ 3/4 percent of the full scale reading.

The electrical current through the electrical heating tape was measured with a Weston Model 433 A.C. ammeter which has three scales: 0 to 5 amperes, 0 to 10 amperes and 0 to 50 amperes. The 0 to 5 ampere and 0 to 10 ampere scales were used. The guaranteed accuracy was $\pm$ 3/4 percent of full scale reading.

CHAPTER IV

EXPERIMENTAL METHODS

Temperature Measurements

The 15 thermocouples indicated on Figure 3 were calibrated in an oil bath which was controlled to ± 0.02 F. These calibrations are given in Appendix B. In general the teflon-covered couples agreed with the thermocouple tables within ± 0.1 F and the stainless-steel-sheathed couples were 0.8 F ± 0.1 F lower than the reference table valves over the calibration range of 100-200 F.

The experimental measurements were taken with a Leeds and Northrup Model 8687 Volt Potentiometer with the reference junction in an ice bath.

Considering both calibration and potentiometer errors, the temperature measurements should be accurate to within 0.2 F. The wall temperature measurements should have this accuracy. Unfortunately the mixing cup temperatures are not this accurate because the flowing streams were not always radially isothermal. Additional thermocouples were installed in the inlet and outlet lines to determine if radial temperature gradients were present. One additional thermocouple was installed near thermocouple 13 in the inlet line. During all subsequent testing the agreement between the two thermoucouples in the inlet line was almost always within 0.1 F indicating that the fluid as it left the pump was essentially isothermal. Two additional thermocouples were installed $\frac{1}{4}$ inch above and $\frac{1}{4}$ inch below thermocouple 12 in the outlet line. At low Re (below 300) the variation in readings between the three thermoucouples was as much as 5 F; however, above Re = 300 the agreement was generally within 0.5 F. A seemingly plausible explanation for this behavior is that the turbulence at higher Re causes the stream to be nearly isothermal in the outlet line. For Re $<$ 300 the outlet temperature was determined from a heat balance.

Heat Loss to the Atmosphere

The exchanger was insulated with fiberglass insulation about 5 inches thick. Heat loss was measured at three heat rates. The specific heat loss $(Q/(T_w - T_a))$ increased as the exchanger wall to ambient temperature difference increased. The experimental values of $Q/(T_w - T_a)$ were 0.5, 0.64 and 0.71 Btu/hr F at $(T_w - T_a) = 23$, 80 and 120 F respectively.

Liquid Volume Flow Rate

The liquid flow rate was measured by closing the gate in the reservoir partition and then measuring the time for the liquid to rise a measured distance.

This method was found to give rise times reproducible to within 2 percent. The reservoir is estimated to be 8 x 8 inches to within 1/16 inch on a side. This would give a potnetial error in area of 2 percent. The volume flow rate should then be accurate to $\pm$ 4 percent.

Power Measurements

The weights were measured to a precision of 0.5 grams. The distance of the weight from the center of rotation was measured on an 18 inch scale. The accuracy of the distance measurement is estimated to be 1/16 inch.

The friction in the exchanger bearings was a significant portion of the total power input to the agitator in many cases. For the 3.500 inch agitator at low torque the bearing friction was as much as 25 percent of the total power. For higher torques, the bearing friction was a much smaller portion of the total power - about 3 percent at the highest torques for the 3.500 inch paddle and less than 2 percent for the 4.039 inch paddle.

The bearing friction was measured with the exchanger empty. Under normal operating conditions with a liquid-full exchanger the bearings were lubricated by the test liquid (see Figure 4); however, to measure bearing friction the exchanger had to be drained; therefore, only the fluid which did not drain from the bearing was left to lubricate. Measurements were made in rapid succession going from low speed to high speed in order to minimize the effect of the residual oil in the bearings becoming hot and therefore less viscous. These measurements were not under the same conditions as during testing because the exchanger contained no oil.

The bearing friction measurements are explained and the data are given in Chapter 5. The curve-fits for computer reduction of the data are also given.

The O-rings were originally placed very near the edge of the Fluorsint bearings. The lip holding the O-rings in place broke off one of the bearings and then a new O-ring groove was cut in the center of the bearings. The bearing friction changed because the new O-ring groove was not the same dimension as the old O-ring groove. There was also an error in power because of friction in the roller bearings on which the motor was balanced. This error, which was undoubtedly negligible, was also relatively greater at low torques than at high torques.

It is rather difficult to estimate the magnitude of errors in the measurement of agitator power requirements because most of the error was a result of bearing friction and the bearing friction measurements could not be made under operating conditions. Probably the best estimate of both systematic and random errors in the agitator power measurements can be obtained by inspecting the data in final correlation form in Figures 8, 9, 10, and 11. Errors in bearing friction result in systematic errors in the agitator power requirement calculated from the experimental data and these systematic errors in turn show up as systematic errors in the conventional power number (P). The errors are manifested on the correlations most generally by a gradual deviation of the data for a particular series of runs from the recommended curve at low torques (i.e., low Re). Little would be gained by listing here maximum deviations from the recommended curves as one can ascertain this and much more by inspecting the final correlations.

Adjustment and Measurement of the Blade to Tube Wall Clearance

The blade diameter was set as desired by use of a cradle. The cradle consisted of two semi-circular wire supports which supported the shafts attached to the blade. When the blade was mounted on its cradle it could be rotated freely and the shafts had very little lateral movement. The cradle was used to assure that the clearance would be the same on both sides of the blade. As the blade was hand-rotated in the cradle a smooth surface was held so that each side of the blade just touched the surface as it moved past. The diameter of the blade was usually measured in five locations along its length; the 4.000 inch blade was measured in six locations. The maximum deviations between these measured diameters for each blade are as follows: 3.500 inch blade, 0.0008 inches; 3.831 inch blade, 0.035* inches; 4.000 inch blade, 0.010 inches; 4.039 inch blade, 0.006 inches.

Operating Procedure

Tests were conducted with and without heat transfer through the exchanger wall. All experimental variables were measured during heat transfer tests. From these measurements agitator power requirements, heat transfer coefficients and axial heat dispersion parameters were determined. Only agitator power requirements were obtained during tests without heat transfer. The operating procedure for the heat transfer tests will be explained first.

To start a series of heat transfer tests the agitator was started and set at an intermediate speed and the electrical power to the wall heating element was turned on. The cooling water was not immediately turned on. The test fluid was allowed to heat to a desired temperature and then the cooling water was turned on and adjusted by means of a needle valve in the cooling water line until the desired temperature

*This deviation is larger than the others because the agitator diameter was adjusted with the aid of a 6 inch metal scale rather than a micrometer. Use of the scale rather than the micrometer was necessary because the Engineering Shop from which the micrometer was borrowed was closed when the blade diameter was changed. The 3.831 inch blade diameter was measured with the micrometer after it was tested.

was maintained. It usually took from one to two hours to obtain quasi-steady-state operation. Completely steady-state operation could not be attained because the cooling water temperature and the electrical power to the heating element varied in an apparently random fashion. These variations were so small, however, as to not significantly affect the accuracy of the experimental measurements.

Once this quasi-steady-state was reached, a series of tests were conducted by incrementally varying the agitator speed. For a single test series runs were made at about 10 to 20 agitator speeds; this usually required 2 to 5 hours. At every agitator speed the following experimental values were recorded in the order given: 15 temperature readings in the numerical order given in Figure 3; voltage drop across exchanger heating element; current through exchanger heating element; the initial cycle timer setting; the time the cycle timer was engaged; the final cycle timer setting; the time for the test fluid to rise 6 inches in the reservoir; the potentiometer setting on the D.C. motor control; the lever arm of the dynamometer weight; and the number of the weight (or weights) on the dynamometer lever arm. It usually took 3 minutes to complete the readings for a single test.

When the agitator speed was changed from test to test the agitator power requirement and the heat transfer coefficient changed. Thus the test fluid bulk temperature and the exchanger wall temperature also changed. After changing the agitator speed, a wall temperature thermocouple (usually thermocouple 6) and the outlet line thermocouple were monitored visually on the spotlight galvanometer in the potentiometer. When these temperatures were so steady that no change could be detected over a period of 2 to 3 minutes or when their dynamic behavior was obviously being influenced primarily by the random fluctuations in line voltage and/or cooling temperature, then the experimental readings were recorded. Generally it took from 10 to 30 minutes to reach lined-out operation. The time between successive tests can be ascertained from the computer printouts of the experimental and reduced data in Appendix D; Central Standard (or Daylight in season) time in minutes was used as test identification.

Successive tests were usually but not always conducted by going to the next higher or lower agitator speed. For many tests (especially in the laminar regime at low agitator speeds) the procedure was to increase and decrease (or vice versa) agitator speed for successive tests. This was done in order to eliminate possible hysteresis effects of developing turbulent flow. Duplicate tests were also quite frequently conducted; these are readily identified from the experimental and reduced data in Appendix D.

Only agitator power requirements were measured during tests without wall heat transfer. The temperature of the test fluid was always below room temperature; it was adjusted to the desired value by cooling the test fluid in the reservoir with city water flowing through the reservoir cooling coils. In a few tests the city water was cooled below its normal seasonal temperature by passing it through a copper tube coil immersed in ice water prior to flowing through the reservoir cooling coils.

Once the test fluid temperature was adjusted to the desired value, the test fluid was circulated through the heat exchanger until the heat exchanger had reached approximately the temperature of the test fluid. Then a series of agitator power requirement tests were conducted by incrementally varying the agitator speed. At every agitator speed the following experimental readings were recorded in the order indicated: the number of the weight (or weights) on the dynamometer lever arm; the lever arm of the dynamometer weight; the wall temperature at the center of the exchanger (thermocouple 6); the temperature just inside the exchanger inlet (thermocouple 14); the temperature just inside the exchanger outlet (thermocuople 15); the initial cycle timer setting; the time the cycle timer was engaged; and the final cycle timer setting.

Successive tests were conducted as fast as the readings could be taken in order to minimize heatup of the test fluid by the viscous dissipation from the rotating agitator. The time between successive readings was approximately one to two minutes.

Selected experimental and reduced data are given in Appendix D.

CHAPTER V

EXPERIMENTAL AND CORRELATIONAL RESULTS FOR AGITATOR POWER REQUIREMENTS

Experimental and Reduced Data

Agitator power requirement data were taken during the heat transfer tests and during the tests without heat transfer. The experimental variables which were monitored are given in Chapter IV in the section entitled "Operating Procedure."

The data were reduced on the 7040 digital computer. Two FORTRAN programs were used in the data reduction. One was used for the heat transfer tests and the other was used for the agitator power requirement tests. FORTRAN listings for both these programs along with experimental and selected reduced data are given in Appendix D.

In order to reduce the agitator power requirement data to correlational form by computer, the following curve-fits were obtained: temperature vs. millivolts from the iron-constantan thermocouple tables; fluid physical properties vs. temperature; and bearing friction vs. agitator speed. Appendix C documents the data on fluid physical properties for Gulf Harmony Oil 151, the only test fluid used for agitator power requirement tests. The curve-fit of the thermocouple tables is documented in the computer programs.

Bearing Friction

The accuracy of the agitator power requirement at low blade speed was affected significantly by bearing friction. The bearing friction was measured under dry conditions (i.e. the exchanger was empty of test liquid). This condition would not be expected to give the same bearing friction as normal liquid-full test conditions; however, the bearing friction could not be measured with liquid in the exchanger. It is not possible to determine experimentally how much the measured bearing friction deviates from that encountered in actual testing. It is most likely, however, that the measured bearing friction is greater than the actual bearing friction because the bearing friction tests were conducted with the exchanger initially at room temperature with the exchanger drained of test fluid. These tests were conducted very quickly (usually less than 5 minutes for a particular blade diameter) so the residual oil in the bearing would not heat very much.

The bearing friction measurements are presented in the graphical form of bearing friction torque vs. agitator speed in Figures 6 and 7 for the four blades tested. You will note from these curves that the bearing friction is not constant from blade to blade nor is it constant for a particular blade as will be noted by inspecting the bearing friction measurements for the 3.500 inch diameter blade. Each time the agitator was removed from the exchanger and reinserted the bearing friction was likely to change. There are several reasons for this; a few of the most important will be mentioned briefly: In inserting the shafts on the agitator through the O-ring seals the O-ring could possibly rotate in its seat or it might be damaged by the shaft being forced through it; the agitator shafts could have been forced out of

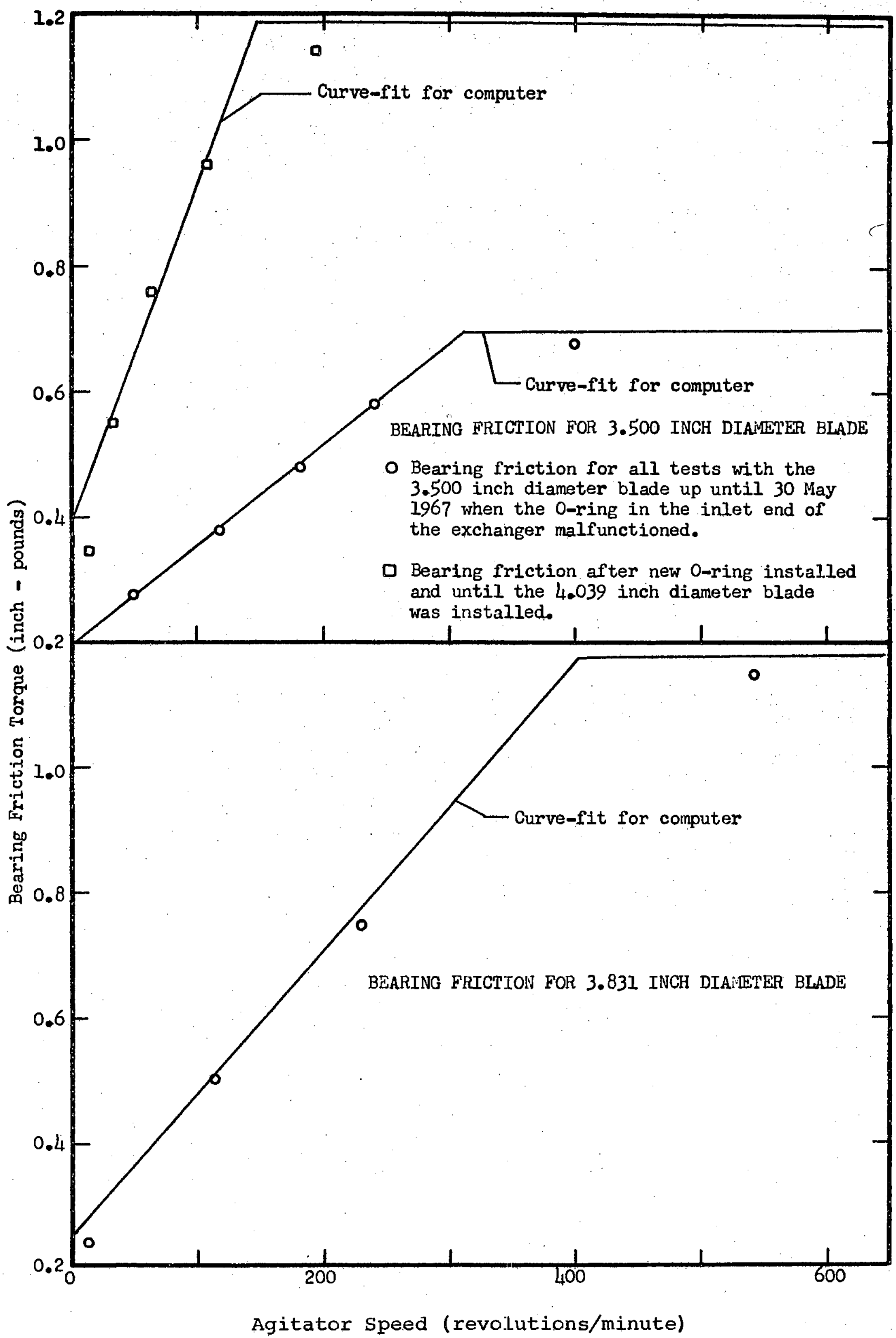


Figure 6. Bearing Friction for the 3.500 and 3.831 inch diameter Blades

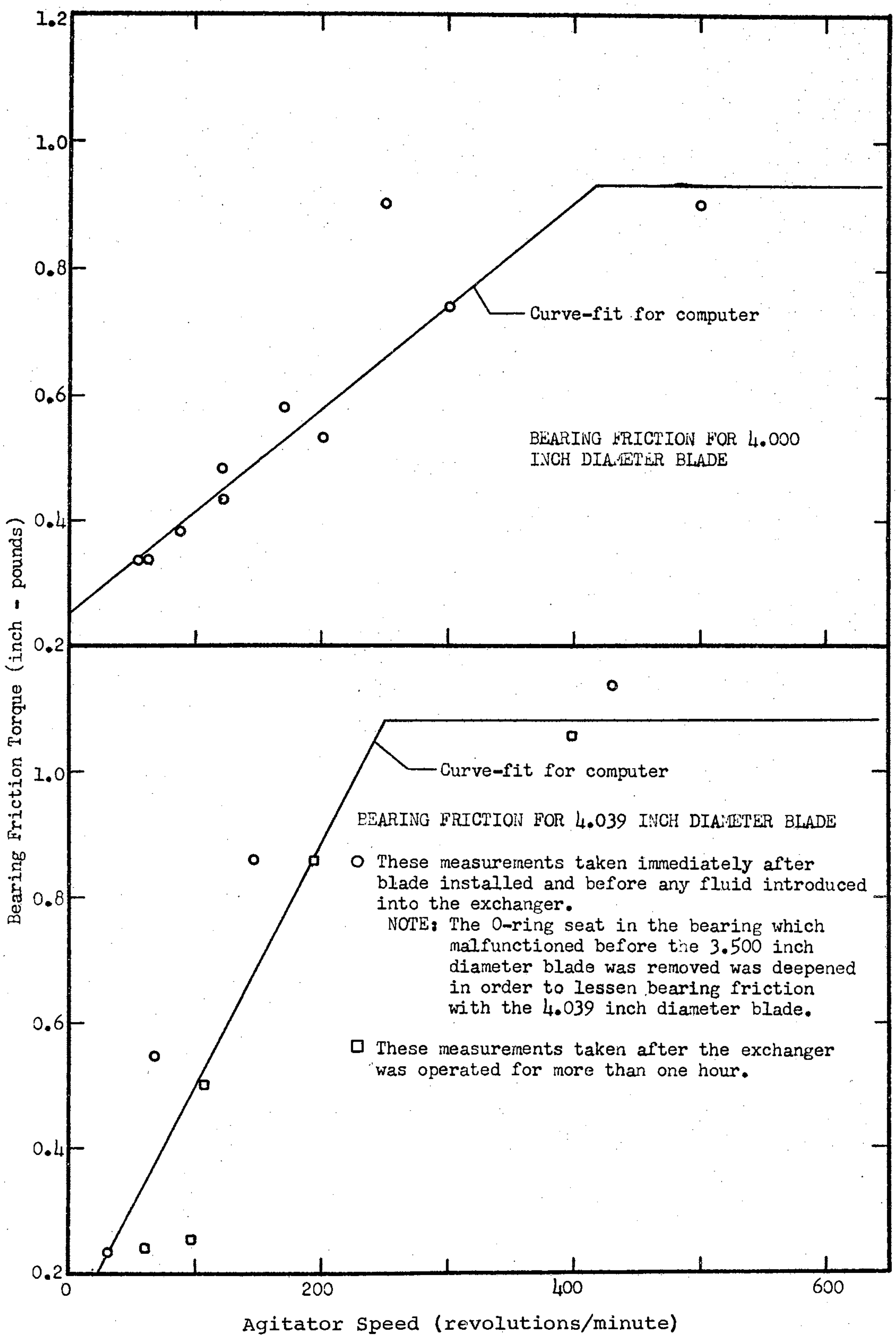


Figure 7. Bearing Friction for the 4.000 and 4.039 inch diameter Blades

alignment while the blade diameter was being adjusted; an O-ring might have had to be replaced because it was damaged during exchanger operation (this did happen while the 3.500 inch diameter blade was being tested); the agitator might not have been placed in exactly the same axial location in the exchanger for every blade; etc. From these comments one might well expect the bearing friction to change from blade to blade and the bearing friction measurements show that it indeed did change. The bearing friction is very nearly linear with agitator speed for low agitator speeds and approaches a constant value for high agitator speeds. The curve-fits of bearing friction torque vs. agitator speed used for computer data reduction are shown as solid lines on the above mentioned figures. For low blade speeds the data were fitted with a linear relationship; above a certain blade speed the data were fitted with a constant bearing friction torque. This is as sophisticated a curve-fit as the data merit. The linear relationship fits the data well at low blade speeds. The bearing friction was a much larger portion of the total motor power output at low blade speeds than at high blade speeds; it was as much as 25 percent of the total power requirements for the 3.500 inch diameter blade at the lowest blade speeds and was about 2 percent for the 4.038 inch diameter blade at the highest blade speed tested. The only adjustment made to the agitator power measurements was that the friction torque was subtracted from the measured torque before the agitator power requirement was calculated on the computer from the appropriate measurements. Both the bearing friction torque and the agitator blade torque are listed in the agitator power requirement data printout in Appendix D.

Later in this chapter it shall be shown that the bearing friction does not have a significant effect on the final power correlation because the slope of the power curve in the viscous regime is known to be −1. This allows one to use the data points in the upper viscous regime, where the bearing friction torque is a relatively small portion of the total motor torque, to establish the position of the power curve for a particular clearance.

Correlation of Power Data

Penney and Bell (36) have analyzed the theoretical work on screw extruders and they have pointed out that theoretical solutions for the creeping flow regime predict that for a flat blade of zero thickness (the agitator power requirement of this system is defined as "bulk power") the agitator power requirement can be represented by the following functional relationship

$$\frac{P_b g_c}{\rho N^3 d^4 L} = \frac{\beta}{\left(\frac{Nd^2\rho}{\mu}\right)} f(c/d,\ d_s/d,\ h/d) \qquad (5\text{-}1)$$

We shall show now that this relationship holds outside the creeping flow regime. In Chapter II it was pointed out that for a geometrically similar system the conventional power number ($\frac{P_t g_c}{\rho N^3 d^5}$) is only a function of the rotary Reynolds number ($\frac{Nd^2\rho}{\mu}$). For a system in which the agitator is nearly as long as the containing vessel the power should be almost directly proportional to the agitator length. This requirement can be satisfied exactly by multiplying the conventional power number by $\frac{d}{L}$, $\frac{P_t g_c}{\rho N^3 d^5}\left(\frac{d}{L}\right) = \frac{P_t g_c}{\rho N^3 d^4 L} = P_{tL}$. This power number, involving $d^4 L$, retains geometrical similarity (it was multiplied by $\frac{d}{L}$) and it satisfies the requirement that the agitator power requirement must be directly proportional to the agitator length. We conclude that

$\frac{P_b g_c}{\rho N^3 d^4 L}$ will correlate the effect of length for systems in which the agitator power is directly proportional to the agitator length.

Therefore the bulk power requirement for a solid flat blade of zero thickness can be represented by the functional relationship of equation (5-1).

One would expect that the power requirement of the knife-edged flat blade of this investigation would exhibit essentially the same power characteristics as a very thin flat blade would exhibit. If this be the case, then correlation of the present agitator power requirement data on a plot of $\frac{P_b g_c}{\rho N^3 d^4 L}$ vs. Re with C/D as a parameter will suffice as a general method for prediction of bulk power requirements for a flat, solid blade. The data are so plotted in Figures 8, 9, 10, and 11 for the four blade diameters tested. Data with and without heat transfer fall essentially on the same curve. Figure 12 is a composite of the correlations for individual clearances.

The slope of the curve of log P_{bL} vs. log Re in the creeping flow regime (Re$<$30) is known from theory to be -1. This fact allows one to establish the position of the curve in the creeping flow regime while neglecting the first four or five data points at the lowest Re where the bearing friction is a greater portion of the total agitator power requirement than at high Re. Thus the agitator power requirement measurements at low torque have little effect on the final correlation of P_{bL} vs. Re.

Additional testing will have to be done to predict the clearance power requirement and to determine if the bulk power requirement and the clearance power requirement are for practical purposes independent and additive.

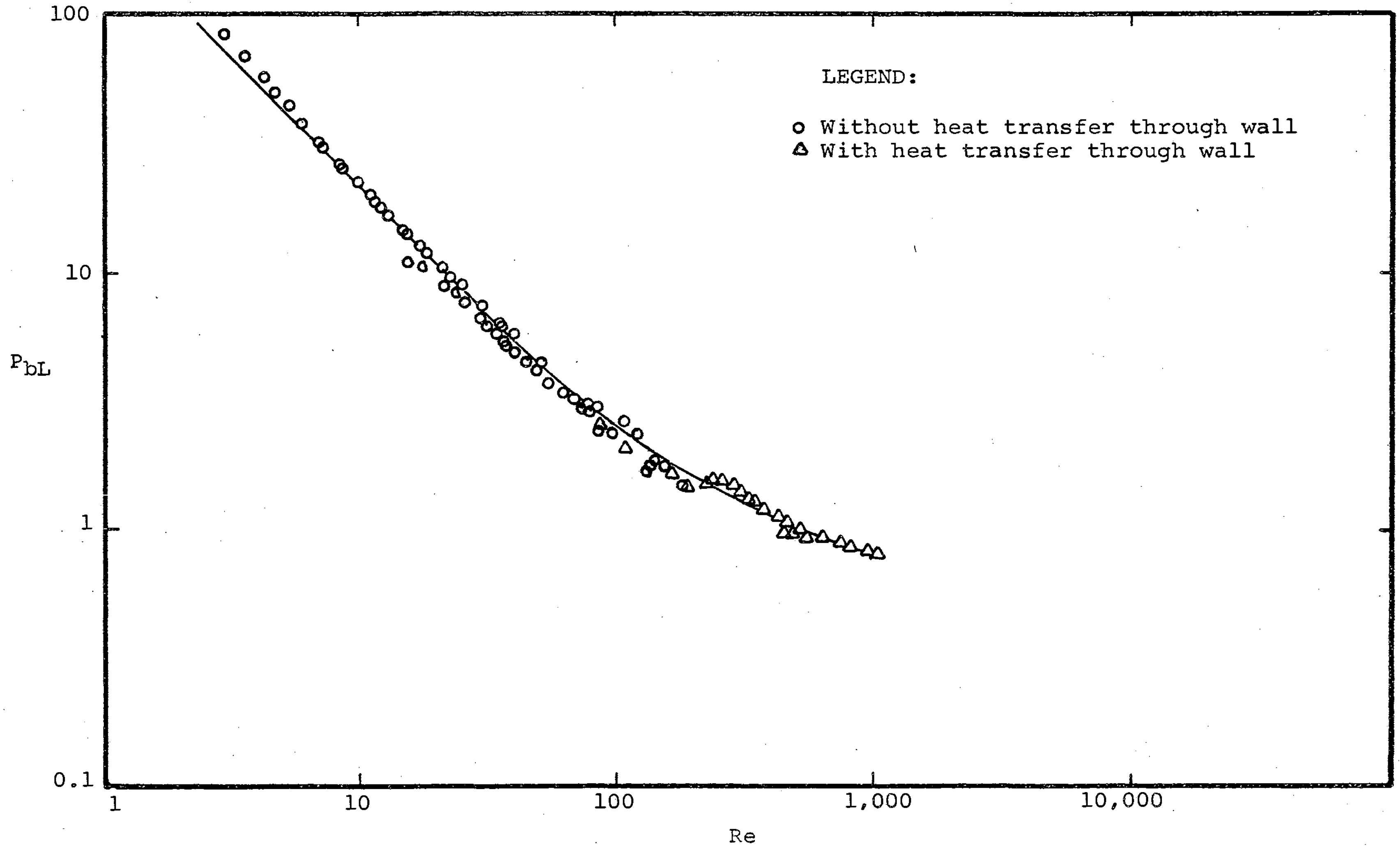


Figure 8. Agitator Power Correlation for the 3.500 inch Diameter Blade

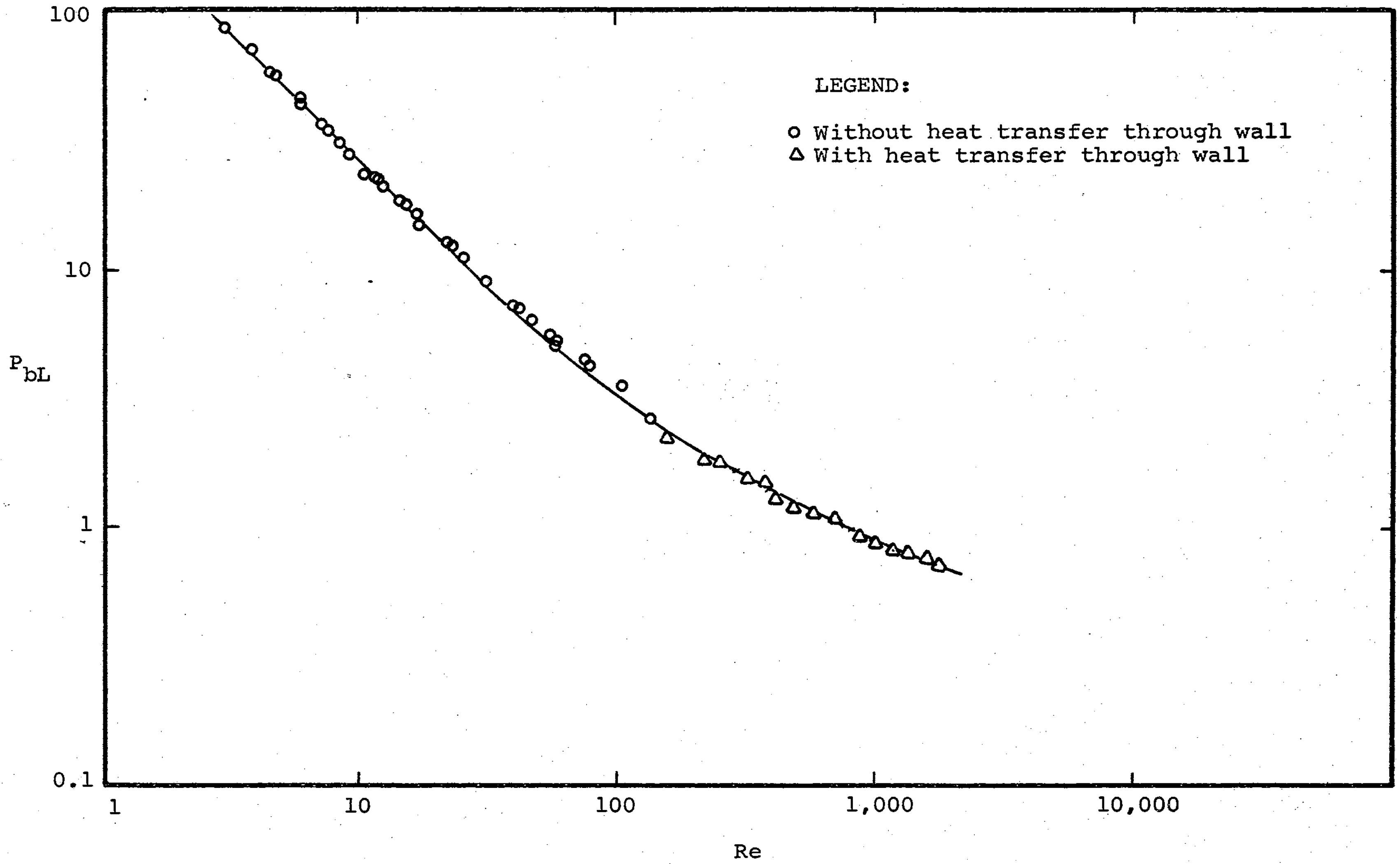


Figure 9. Agitator Power Correlation for the 3.831 inch Diameter Blade

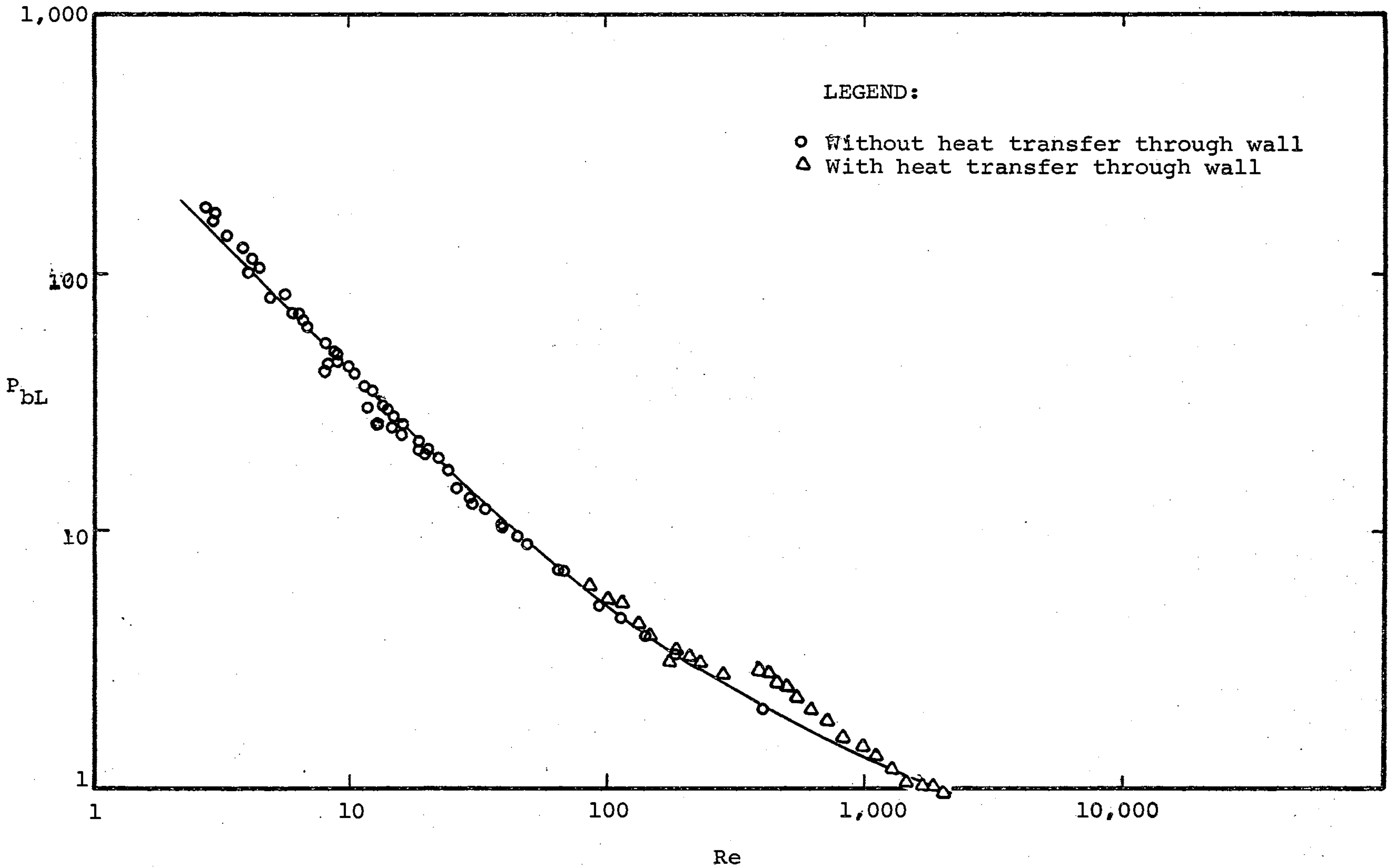


Figure 10. Agitator Power Correlation for the 4.000 inch Diameter Blade

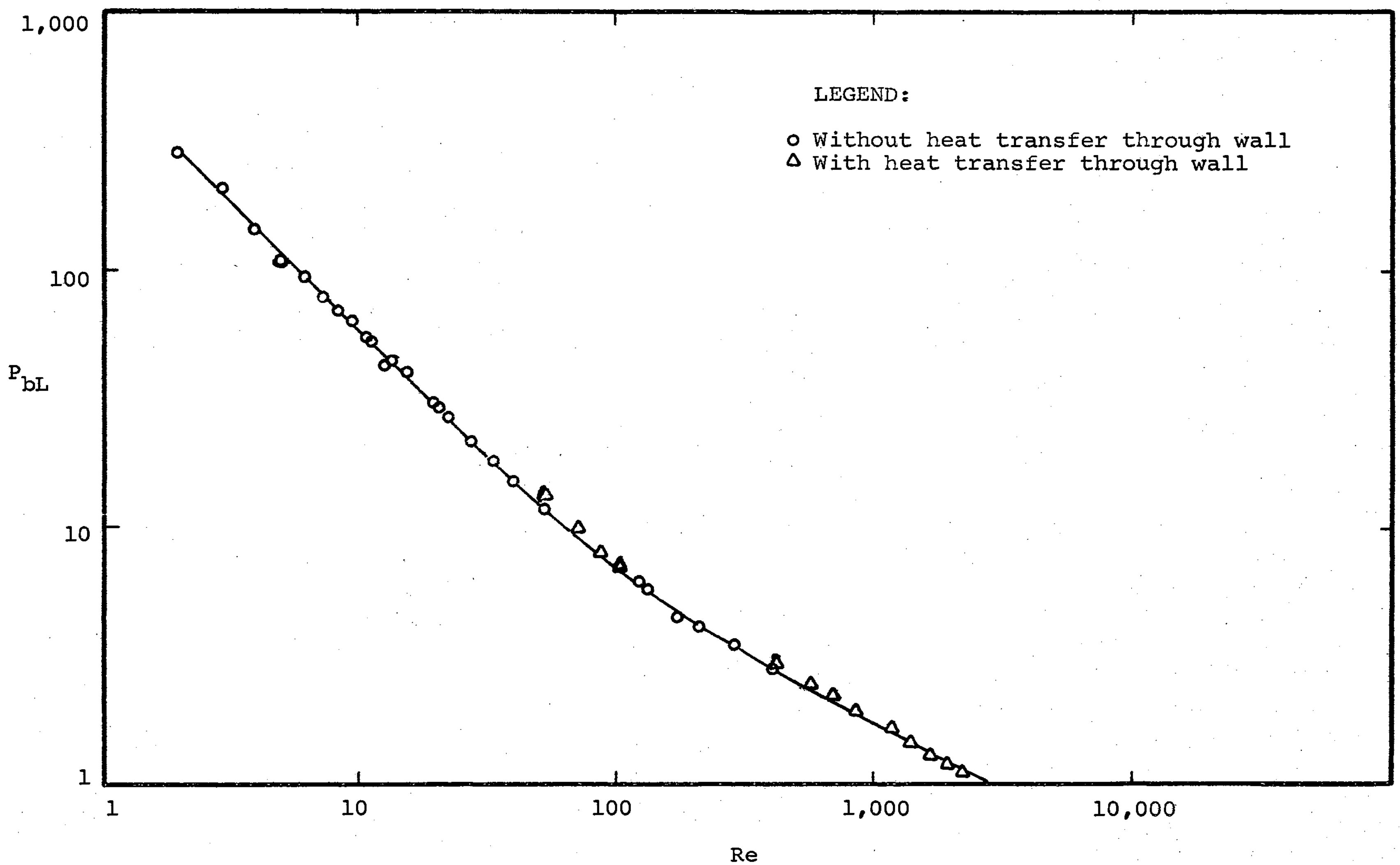


Figure 11. Agitator Power Correlation for the 4.039 inch Diameter Blade

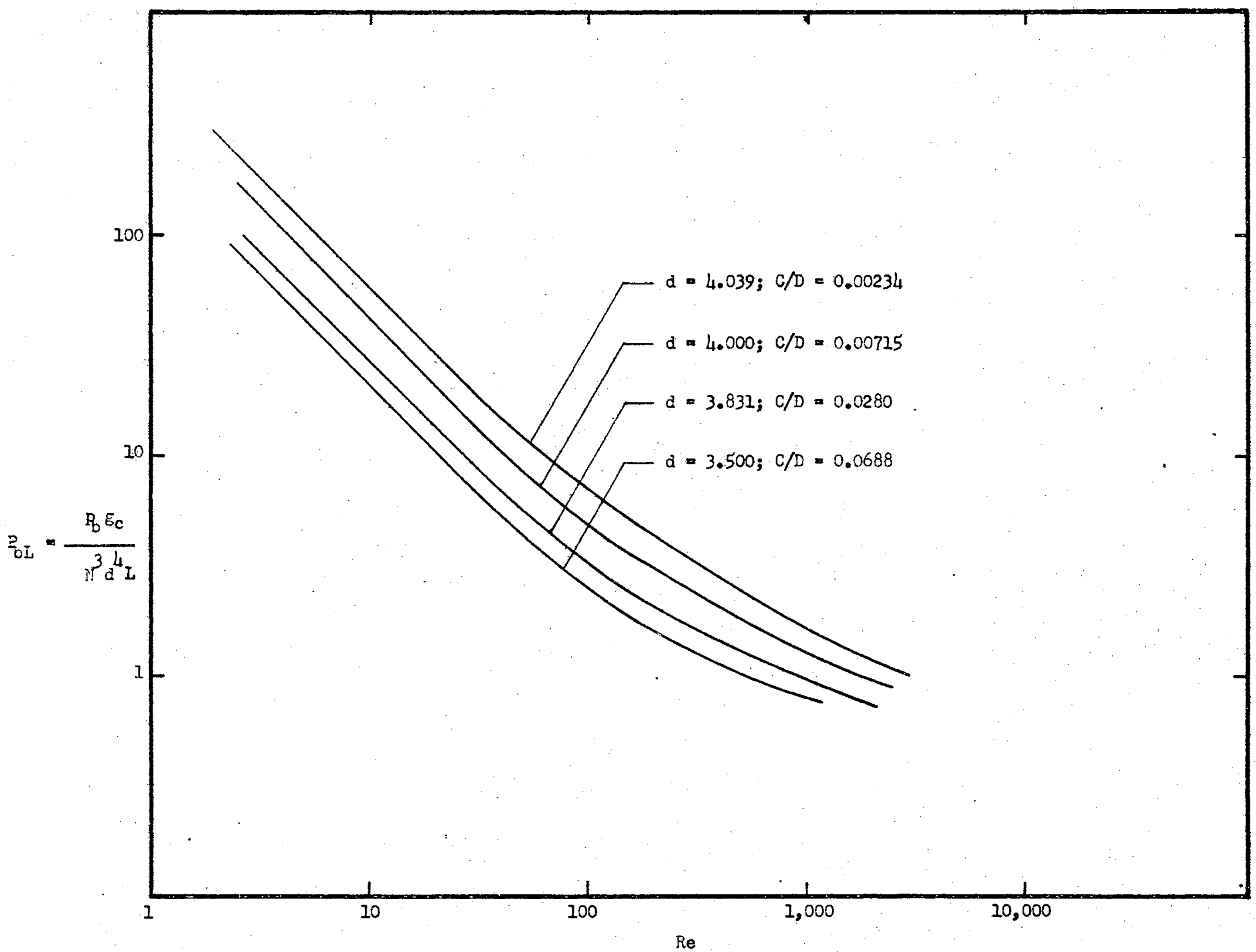


Figure 12. Correlation for Bulk Agitator Power Requirements of Flat Paddle Agitators

The only other reasonably similar geometry for which data are available are anchor agitators. The power results of Uhl and Voznick (48) and Beckner and Smith (1) for anchors are compared with the present results in Figure 13. P_{tL} is plotted vs. C/D at Re = 10. (The straight-line correlations for different C/D are parallel in the creeping flow regime; therefore, the value of Re chosen for comparison is immaterial as long as it is in the creeping flow regime.) All the data essentially fall on straight lines. Beckner and Smith's (1) data are compared using both the length of the agitator in the power number and the effective peripheral length (EPL = L + D/4) in the power number as suggested by Uhl and Voznick (48). The data correlate better if the length of the agitator is used rather than the EPL.

If end effects are negligible, this agreement between the flat blade and the anchor means that the blade arm width has little effect on power over a wide range of blade arm widths. Uhl and Voznick (48) found that a 2 inch and a 3 inch arm on a 24 inch diameter anchor agitator gave essentially the same power consumption. This indicates that the power drawn by the anchors is almost all bulk power. Penney and Bell (36) estimated that the clearance power drawn by the anchor agitators tested by Uhl and Voznick (48) was a maximum of 8 percent of the total power consumption. One would expect that power consumed as a result of end effects in the present investigation would at least equal or exceed the power consumed as a result of end effects of the anchor agitators because the agitator of this investigation had two ends whereas an anchor agitator has only one end which consumes power. One would not expect the free surface in the anchor tests to increase the power requirement over that experienced at a solid surface.

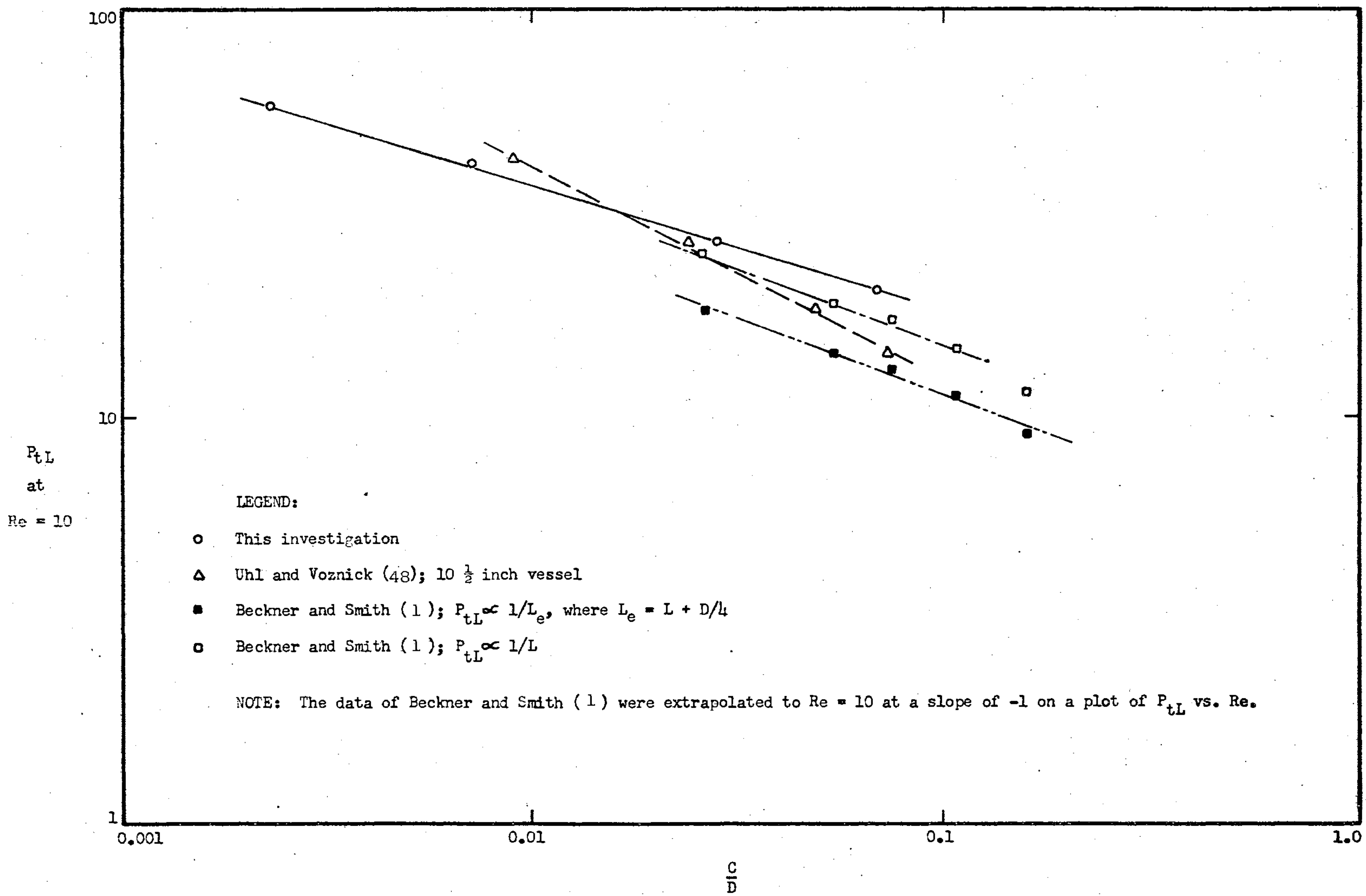


Figure 13. Comparison of the Dependence of P_{tL} on $\frac{C}{D}$ for Various Data at Re = 10

A comment is in order here concerning the inclusion of C/D raised to a constant exponent in the power number. As Figure 13 indicates this might suffice to correlate power in the creeping flow regime, although one would not expect bulk power to satisfy any such relation as the clearance approaches zero. The effect of clearance is very likely different in the turbulent regime than in the laminar regime. If this be the case, then C/D cannot be included in the power number if both laminar and turbulent data are to be correlated on the same chart. In fact, Uhl and Voznick's (48) data for the 24 inch diameter anchor indicate that the clearance has little effect on power at Re = 3,000. Bates et al. (46) have pointed out that inclusion of geometrical ratios in the power number is fundamentally unsound.

CHAPTER VI

EXPERIMENTAL AND CORRELATIONAL RESULTS FOR HEAT TRANSFER

Experimental Results

Test were conducted with both ethylene glycol (the physical properties of the test fluids are given in Appendix C) and Gulf Harmony Oil 151. Testing was done with ethylene glycol only for the 4.000 inch diameter blade.

The experimental variables which were monitored are given in Chapter IV in the section entitled "Operating Procedure."

Wall temperature profiles and inlet and outlet temperatures for selected tests are presented in Figures 14, 15, 16, and 17 for each of the four blade diameters tested. Data are presented for the creeping flow ($Re < 30$) and transition ($150 < Re < 700$) regimes for each blade diameter. Recall that in Chapter 5 we explained that as far as heat transfer is concerned the flow is fully turbulent at Re = 700, although it is not fully turbulent as far as agitator power requirements are concerned until Re = 10,000.

In the turbulent regime the wall temperature is almost linear except for a slight skewing down at the exchanger ends, indicating that the heat transfer coefficient is almost constant along the length of the exchanger. The skewness at the ends is probably a result of conduction through the plexiglass endplate to the atmosphere or from the

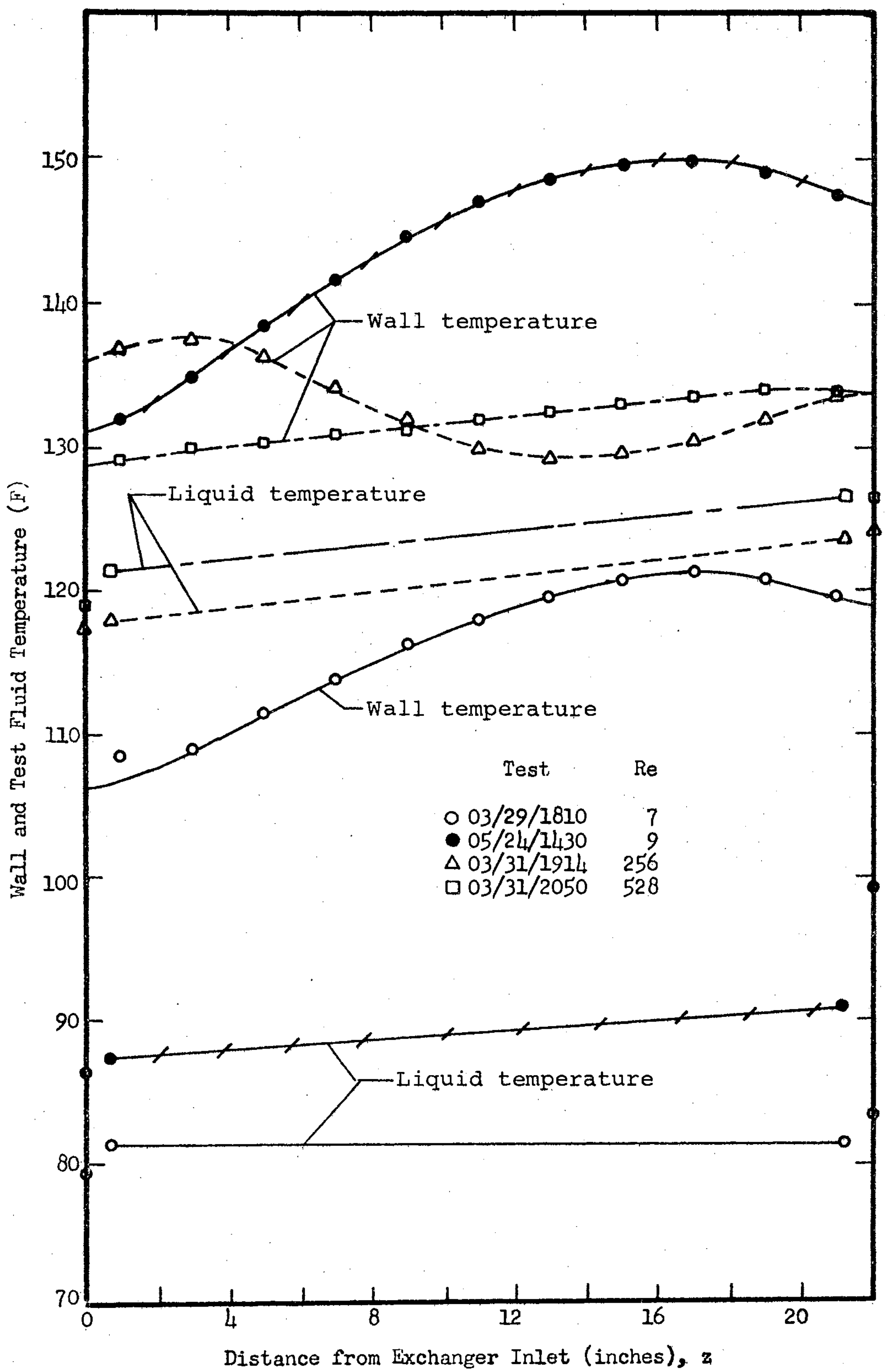


Figure 14. Typical Wall Temperature Profiles for the 3.500 inch Diameter Blade

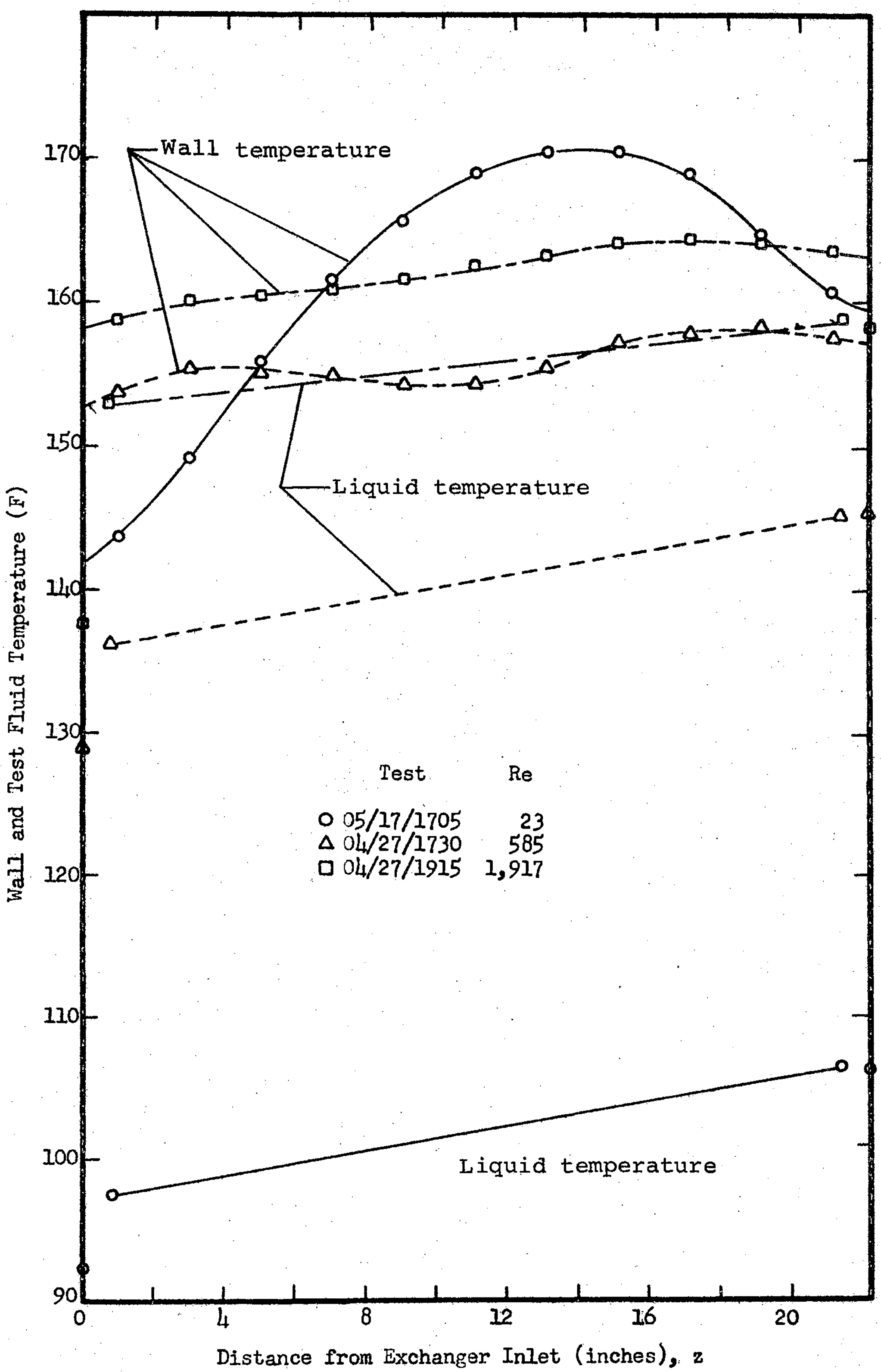


Figure 15. Typical Wall Temperature Profiles for the 3.831 inch Diameter Blade

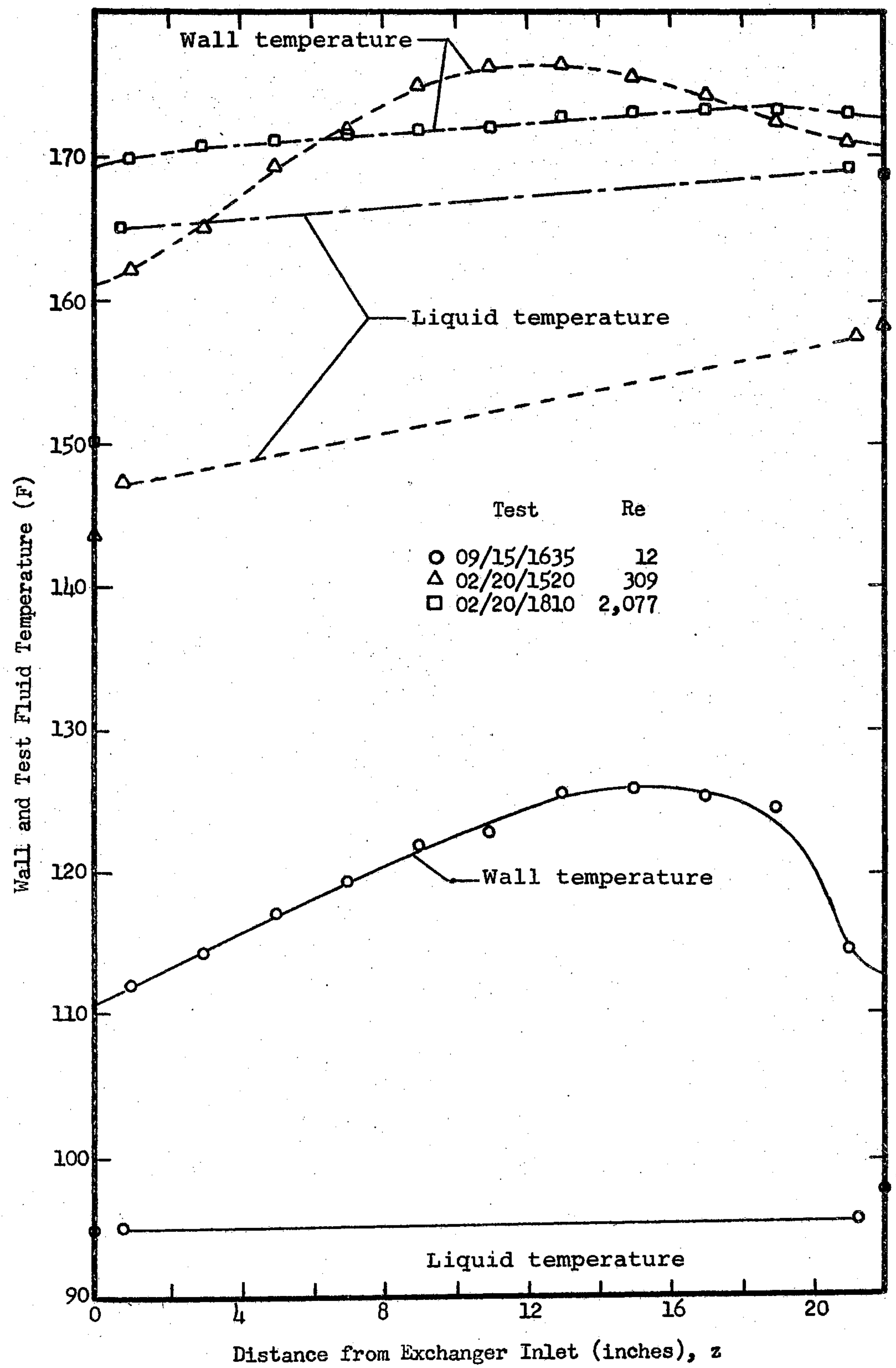


Figure 16. Typical Wall Temperature Profiles for the 4.000 inch Diameter Blade

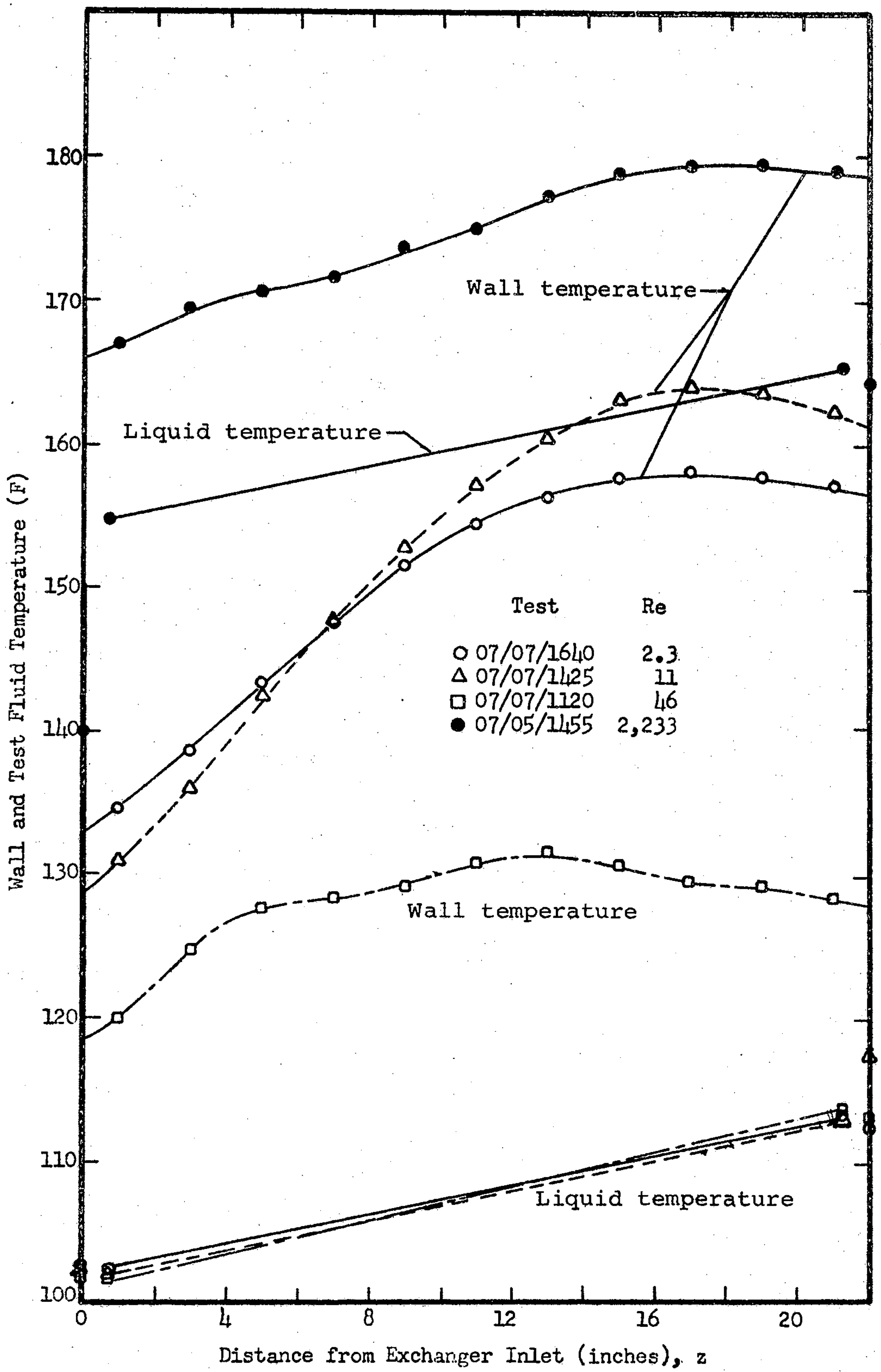


Figure 17. Typical Wall Temperature Profiles for the 4.039 inch Diameter Blade

endplate to the test liquid.

In the laminar regime the wall temperature is skewed down at both ends of the exchanger but more so near the entrance than near the exit. Due to the development of an adverse temperature gradient as a result of axial flow, the heat transfer coefficient would be expected to be higher near the entrance than near the exit; probably it is this high heat transfer coefficient near the entrance which causes the wall temperature to skew down near the entrance. The drop in wall temperature near the exit is probably a result of conduction to the endplate and very possibly the result of an increased heat transfer coefficient due to end effects. It would be desirable to determine quantitatively how the heat transfer coefficient varied near the outlet end; unfortunately not enough wall temperature measurements were taken to accurately determine the axial variation of heat transfer coefficient near the exchanger ends.

In the transition regime, the wall temperature profiles for the 3.500 inch diameter and the 3.831 inch diameter blade exhibit a minimum near the center of the exchanger rather than near the ends. Thus in this region the heat transfer coefficient is highest near the center of the exchanger. This anomalous behavior may be a result of secondary flow in the exchanger.

The temperature profiles for the 4.039 inch diameter blade in the transition and turbulent regime are not nearly so smooth as those for the other blades. This behavior is probably a result of the clearance not being constant along the length of the exchanger. The clearances reported are average clearances. It is estimated the clearance for the 4.039 inch diameter blade might vary as much as 0.005 inches. This means that the clearance for the 4.039 inch diameter blade might have varied from 0.005 to 0.0015 inches. This variation in clearance would be expected to have little effect for the other blades.

Calculation of Experimental Heat Transfer Coefficients

The experimental heat transfer coefficient was calculated at 14 inches from the inlet end of the exchanger. At this location the correction of axial conduction in the exchanger wall is most accurate and the heat transfer coefficient is influenced the least by end effects.

The experimental heat transfer coefficient was computed as follows:

$$h_{z=14} = \frac{(q_F)_{z=14}}{(T_w - T_b)_{z=14}} \qquad (6\text{-}1)$$

where

q_F = heat flux to the test fluid at z = 14 inches from the exchanger inlet.

$$(T_w)_{z=14} = \frac{T_4 + T_5}{2} \qquad (6\text{-}2)$$

$$(T_b)_{z=14} = \frac{8}{22} T_0 + \frac{14}{22} T_L \qquad (6\text{-}3)$$

A linear temperature rise is assumed between the fluid temperature just inside the exchanger inlet (T_0) which is T(14) on Figure 4 and the fluid temperature just inside the exchanger outlet (T_L) which is T(15) on Figure 4. For the condition of axially constant heat flux to the fluid the temperature rise of the test fluid would be essentially linear. The heat flux to the fluid was not axially constant because of axial conduction in the exchanger wall. In order to minimize the error in the calculated bulk fluid temperature due to nonuniform heat flux axially, the temperature rise of the test fluid through the exchanger was kept relatively small compared to $(T_W - T_b)_{Z = 14}$ except in the turbulent regime where the wall heat flux was nearly constant axially. Therefore, the error in the calculated bulk fluid temperature is not expected to significantly affect the accuracy of the experimental heat transfer coefficient.

Due to axial conduction in the aluminum wall, the heat flux to the fluid (q_F) at any axial location is not in general equal to the constant heat flux from the heating element (q_H). The heat flux to the fluid can be calculated from the experimental wall temperature profile. By assuming negligible radial wall temperature variations and constant heat flux from the heating element, equation E-2 below is obtained in Appendix E by a heat balance on an element of wall.

$$\frac{q_F}{q_H} = 1 + \frac{k_w A_w}{q_H P} \frac{d^2 T_w}{d z^2} \qquad \text{(E-2)}$$

The second derivative of wall temperature with respect to exchanger length was calculated by finite differences using the experimental wall temperature measurements. In Appendix E the calculation procedure is explained and the finite difference calculations are compared with graphical methods. The finite difference method was compared with the hand graphical method for a series of 10 tests with the 3.500 inch diameter blade. The maximum deviation of $(q_F/q_H)_{Z = 14}$ was 7.5 percent and the average absolute deviation for the 10 tests was 2.4 percent. The finite difference method appears to give less test to test random error than the hand calculation method. The ratio q_F/q_H was as low as 0.65 in the laminar regime and was essentially 1.0 in the turbulent regime.

Correlation of Data

Uhl and Voznick (48) for anchor agitators show that in the turbulent regime heat transfer is correlated very well by a plot of $\frac{Nu}{Pr^{1/3}} \phi^{0.18}$ vs. Re, if only agitator rotation affects the heat transfer. This is the correlating mechanism which Uhl and Voznick (48) use in the laminar and lower turbulent regimes. In the laminar regime the straight-line correlations of $\frac{Nu}{Pr^{1/3}} \phi^{0.18}$ vs. Re on log-log graph paper has a positive slope of $\frac{1}{2}$ which makes the exponent on Re equal $\frac{1}{2}$. Their correlation then predicts that the heat transfer coefficient is proportional to the fluid viscosity of the -1/6 power. In the creeping flow regime for isothermal radial conditions, however, the fluid flow patterns are independent of the fluid viscosity; therefore, the heat transfer coefficient should be independent of the fluid viscosity. In order for a plot of $\frac{Nu}{Pr^{1/3}} \phi^{0.18}$ vs. Re to correlate heat transfer in the creeping flow regime the slope of the resulting straight-line correlation must be 1/3 so that the viscosity in both Pr and Re will cancel.

The heat transfer results of this investigation are correlated by this method in Figures 18, 19, 20 and 21. Data were taken for ethylene glycol only with the 4.000 inch diameter blade and only in the turbulent regime. The data for oil and ethylene glycol agree very well. In the turbulent regime the data for all clearances very nearly coincide. In Figure 22 the correlation of the present investigation is compared with the correlation of Uhl and Voznick (48) for anchor agitators. Again the correlations very nearly coincide in the turbulent regime. As a further check of the generality of this correlation in the turbulent regime, Uhl (46) has compared Votator data in the turbulent regime with

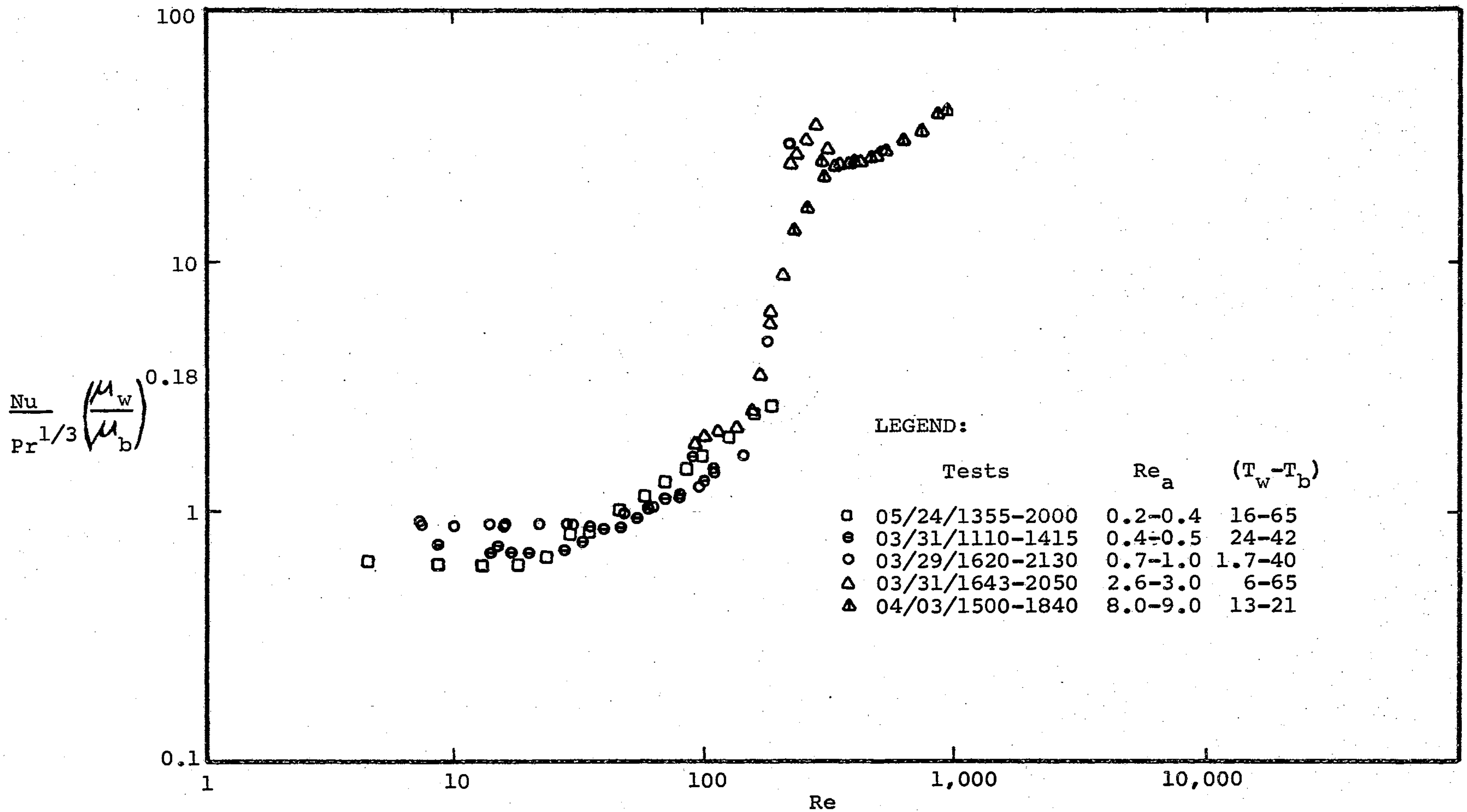


Figure 18. Heat Transfer Correlation for the 3.500 inch Diameter Blade

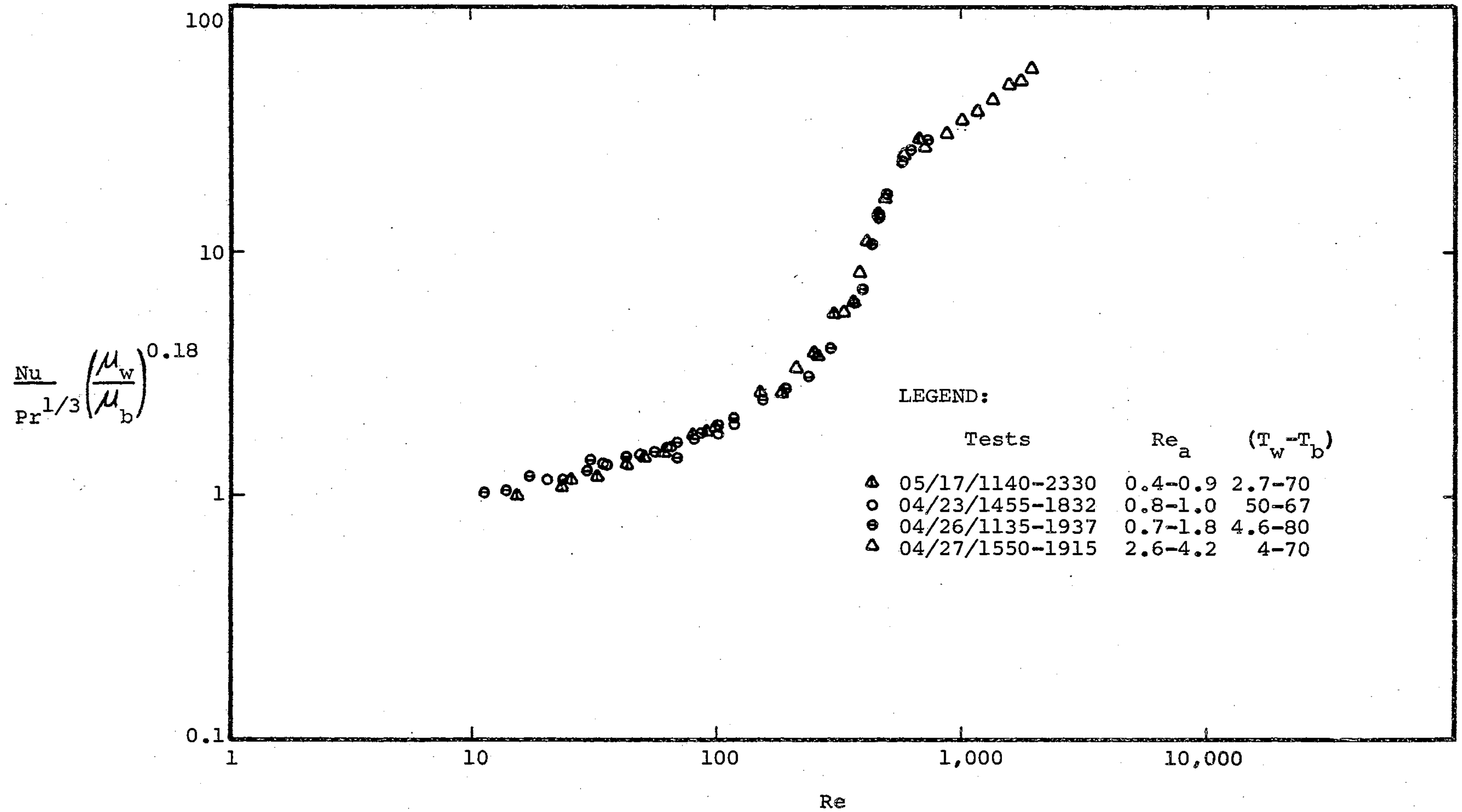


Figure 19. Heat Transfer Correlation for the 3.831 inch Diameter Blade

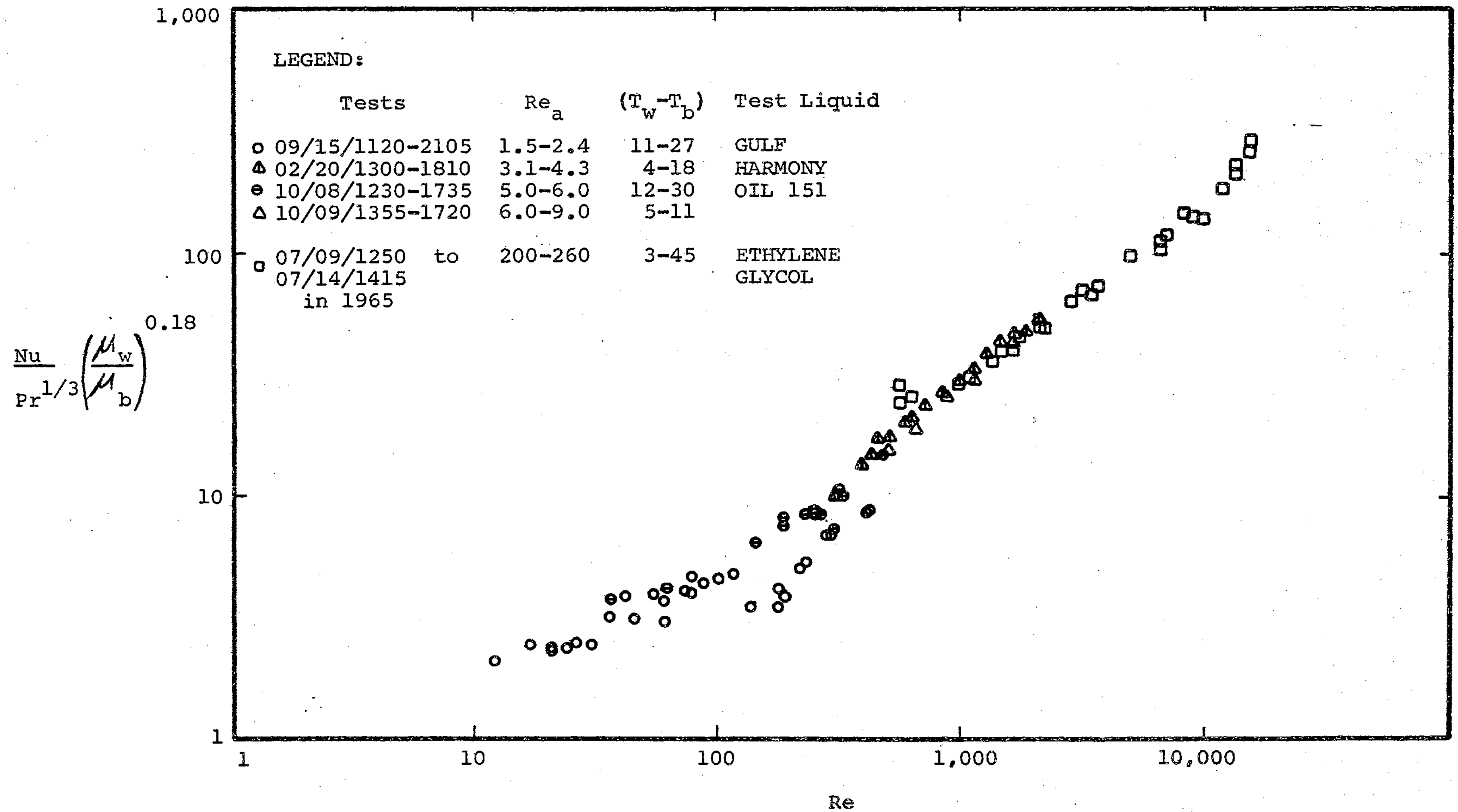


Figure 20. Heat Transfer Correlation for the 4.000 inch Diameter Blade

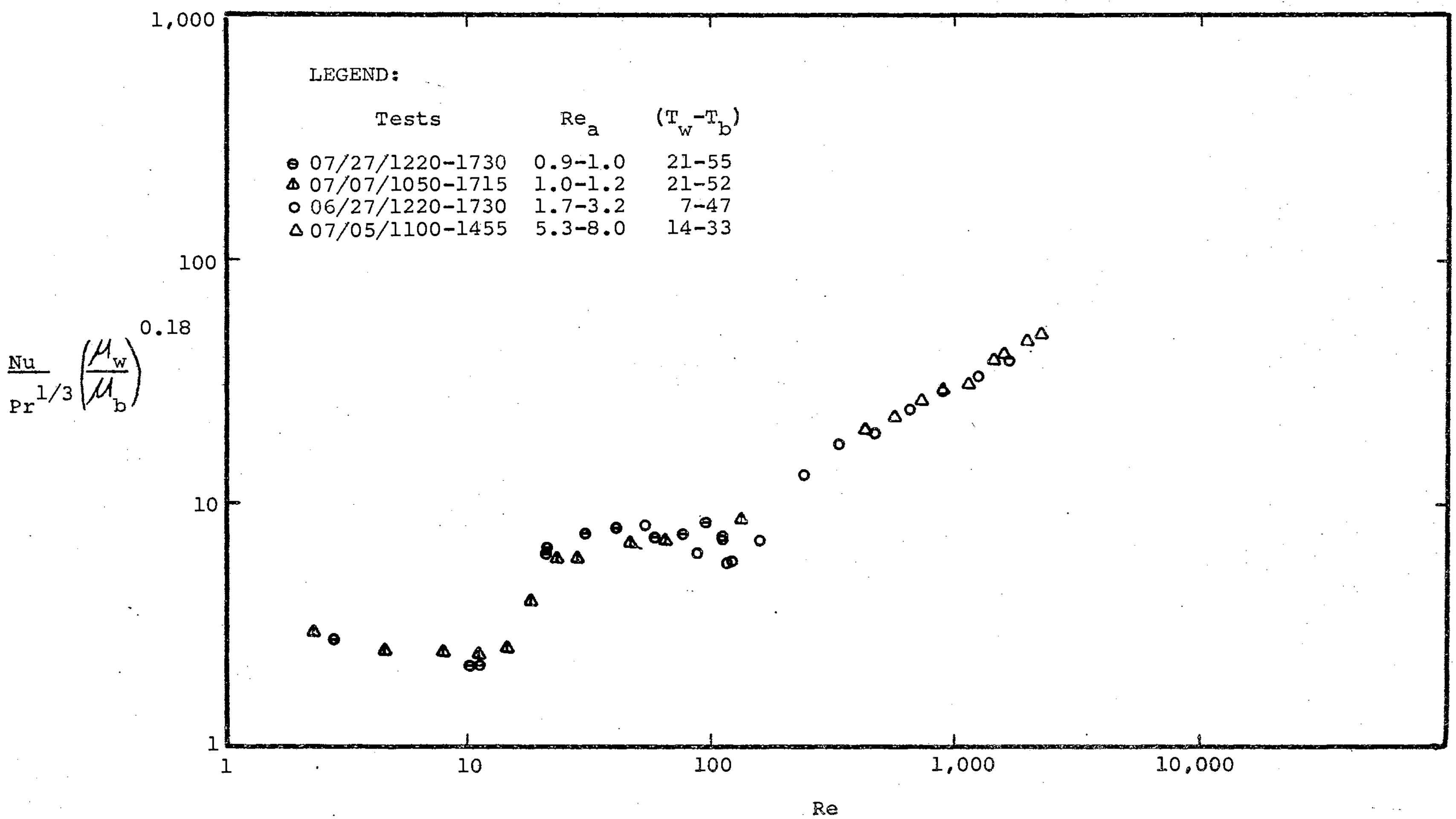


Figure 21. Heat Transfer Correlation for the 4.039 inch Diameter Blade

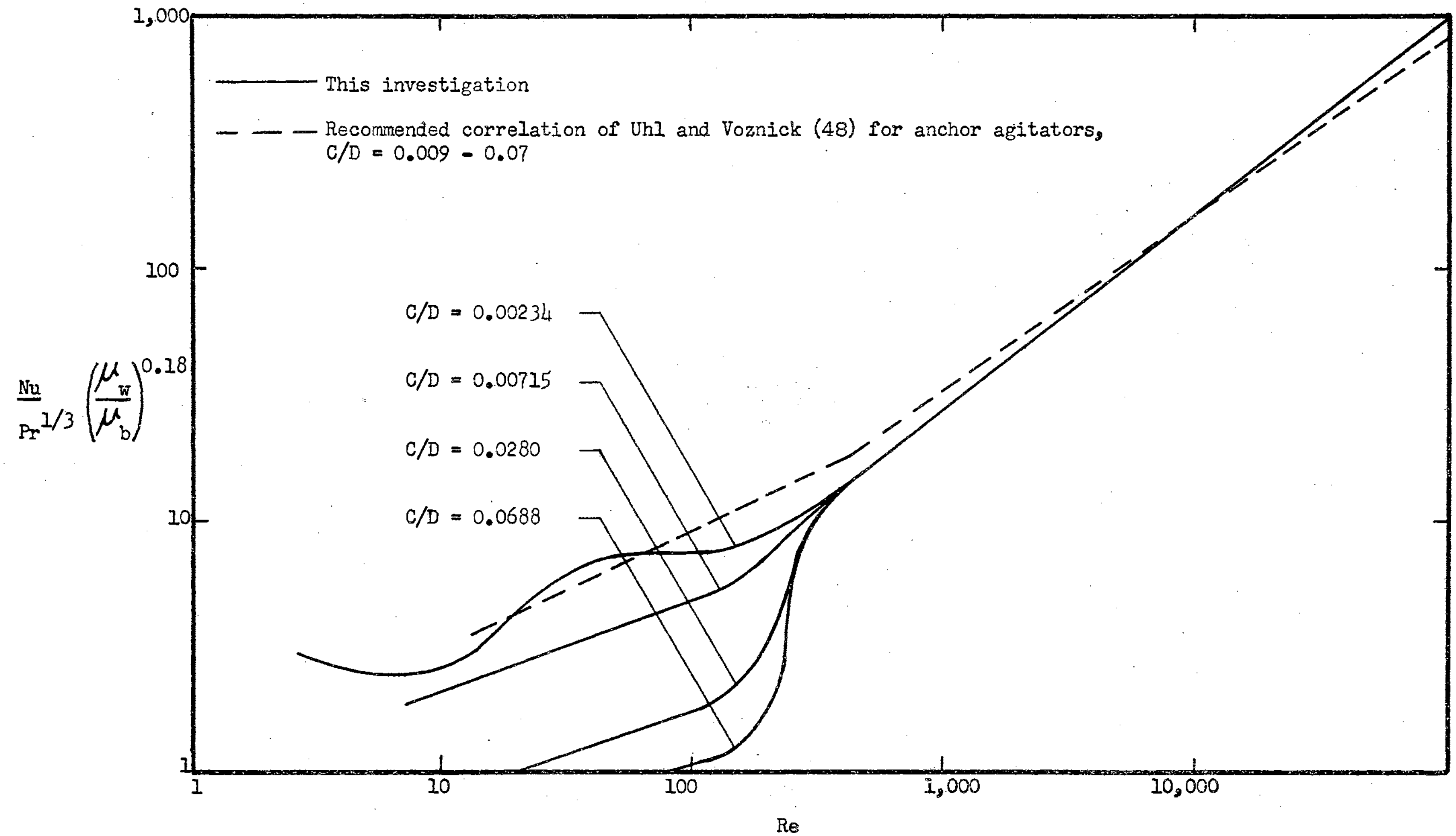
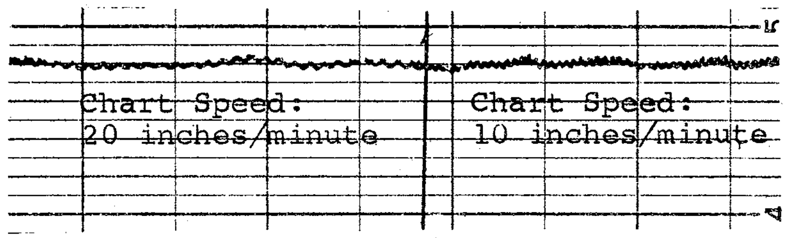


Figure 22. Heat Transfer Correlation

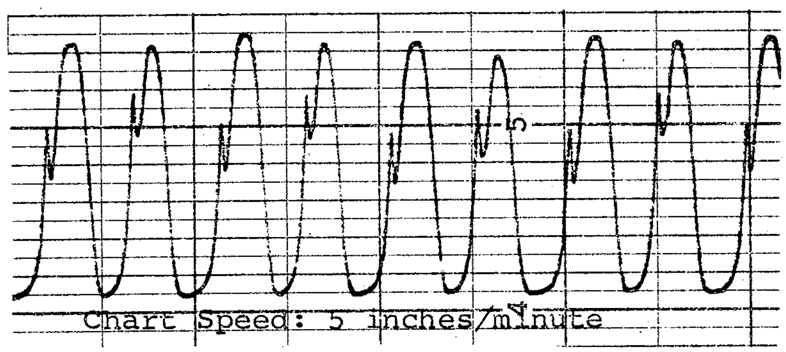
the suggested correlation of Uhl and Voznick (48) and has found good agreement. This indicates that neither clearance nor geometry has a significant effect on heat transfer in the turbulent regime.

Now consider the laminar regime where free convection and axial flow are likely to affect the heat transfer. In the creeping flow and transition regimes (as noted in Chapter II the creeping flow regime extends up to approximately Re = 30) the data of this investigation are obviously affected by axial flow and probably by free convection also. The data for the 3.500 inch diameter blade in Figure 18 show a pronounced effect of axial flow below Re = 30. The data for the 3.831 inch diameter blade also show a slight dependence on axial flow for Re below 100. The data for the 4.000 inch diameter blade are scattered in the laminar regime due to greater errors for this blade in computation of the second derivative to obtain the wall conduction correction. For the 4.039 inch diameter blade it appears that free convection affects the heat transfer at the lowest blade speeds (as low as 5 rev./min.). The increase in heat transfer below Re = 10 is probably due to the blade speed being so low that the buoyancy forces have sufficient time during a single revolution of the blade to establish free convection flows before the gravity vector changes direction with respect to the blade velocity vector. The effect of axial flow is probably negligible for the 4.000 and the 4.039 inch diameter blades because the heat transfer due to the blade rotation is so much higher than for the 3.500 inch diameter and the 3.831 inch diameter blades.

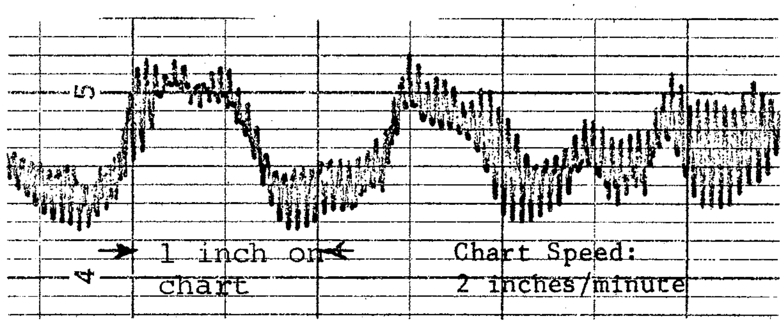
There was also some anomalous behavior of the outlet temperatures observed for the 4.039 inch blade which may have some bearing on the minimum in the heat transfer in the laminar regime. Figure 23 presents



Time of Test: 07/07/1715
Agitator Speed: 249.2 revolutions/min.
Re: 133.5
Temperature Scale on Chart: 0.5 mv/in.



Time of Test: 07/07/1605
Agitator Speed: 5.2 revolutions/min.
Re: 2.6
Temperature Scale on Chart: 0.5 mv/in.



Time of Test: 07/04/1715
Agitator Speed: 40.7 revolutions/min.
Re: 21.3
Temperature Scale on Chart: 0.5 mv/in.

Figure 23. Strip Chart Recorder Traces of the Millivolt Output of Thermocouple 12 in the Exchanger Outlet Line for Selected Tests with the 4.039 inch Diameter Blade

strip charts from a Brush Recorder of the temperature in the outlet line for the tests below Re = 300. At Re = 130 all temperatures were steady with little fluctuation. At about Re = 100 the outlet temperature started fluctuating ± 3 °F in a random manner; at about Re = 20 the random fluctuations were about ± 5 °F, for which the total fluctuation is approximately equal to the temperature rise through the exchanger. The period of the fluctuations varied from about ½ to 1 minute. At Re below 10 the random fluctuations in outlet temperature did not exist although periodic fluctuations caused by the rotating blade did exist. We do not know how this instability might affect the heat transfer. The instability was not noted for blades other than the 4.039 inch diameter blade. It was very noticeable on the potentiometer. The potentiometer galvanometer would go all way off scale on both ends during the greatest fluctuations. For other blades at the same Re the galvanometer was steady.

Because free convection and axial flow affect the heat transfer at low blade speeds, the slope of the curve of $\frac{Nu}{Pr^{1/3}} \phi^{.18}$ vs. Re cannot be established with certainty in the upper creeping flow regime. If this correlating method is correct, however, then in the creeping flow regime the slope must be 1/3. With the data available in the creeping flow regime, there is certainly no justification for using any other correlating method than the one used. In order to compare the heat transfer for the various clearances, the slope is assumed 1/3 and Figure 22 presents a composite of all the data.

There are some very important points to be made from this figure. The clearance has a great effect on the heat transfer in the laminar regime but not in the turbulent regime. In the transition regime the

the heat transfer increases greatly over a very narrow range of Re. For the 3.500 inch diameter blade a ten-fold increase in heat transfer is obtained as Re doubles from 150 to 300. Clearance and agitator geometry have little effect on heat transfer in the turbulent regime. If Uhl and Voznick's (48) data in the laminar regime are not influenced by free convection or other extraneous effects, the agitator geometry does have a great effect on heat transfer in the laminar regime, especially for large clearances. The largest clearance used in this investigation gave heat transfer rates 1/7 those of the largest clearance used by Uhl and Voznick (48) at Re = 100. The largest clearances of this investigation had approximately the same C/D as the largest clearances used by Uhl and Voznick.

Discussion of the Possible Effects of Axial Flow and Free Convection on the Experimental Heat Transfer Coefficient

After calculating the experimental heat transfer coefficient the next consideration is whether this coefficient is influenced by extraneous effects, i.e., effects on other than agitator rotation.

The primary factors which can affect the heat transfer (assuming constant fluid physical properties) are (a) free convection and (b) axial flow. Both these factors should affect the heat transfer more at low blade speeds than at high blade speeds.

The driving force for free convection is gravity, which always acts in a vertical plane. Because the rotating blade, and thus most of the test fluid, continually changes position with respect to the gravity vector, the free convection tends to be canceled by blade rotation and also at high blade speed the rotational convective forces tend to overshadow the free convection forces. Also free convection generally diminishes as the blade speed increases because the bulk fluid to exchanger wall temperature in general decreases as the blade speed increases. Thus free convection would only be expected to affect the heat transfer at very low blade speeds (i.e., low Re).

The axial flow produces fluid flow which is essentially perpendicular to that produced by blade rotation. The effect of axial flow can be determined experimentally by conducting tests at various axial flow rates. We attempted here to conduct tests at sufficiently low axial flow rates so that the heat transfer coefficient was affected only by blade rotation. The final heat transfer correlation in Figures 18, 19, 20 and 21 indicate that we were successful in attaining this objective except at very low Re.

CHAPTER VII

EXPERIMENTAL AND CORRELATIONAL RESULTS FOR THE EFFECT OF BACKMIXING ON THE MTD

Analysis of Experimental Data

The only experimental measurement made in this investigation which can be used to determine the true MTD and thus the effect of backmixing on the MTD is the temperature just inside the inlet line of the exchanger (T_O). The dimensionless parameter involving the temperature just inside the inlet line, which can be related to analytical solutions of the dispersion model, is the temperature jump ratio $\frac{T_O - T_i}{T_L - T_i} = \theta$ where T_i is the temperature at the exchanger inlet and T_L is the temperature at the exchanger outlet.

Figure 24 presents temperature jump ratio data from selected tests plotted vs. Re. These data were selected in order to show differences between data from different blade diameters operating at essentially the same conditions and to show the effect of axial flow rate for a particular agitator. Note the great difference between the data for the 3.500 inch diameter agitator and the data for the 4.039 inch diameter agitator taken 06/27/1220 although both sets of data are for essentially the same operating conditions. Also note that the two series of tests for the 4.039 inch diameter agitator show that the temperature jump ratio is higher (i.e. the MTD is lower) for lower axial flow rates.

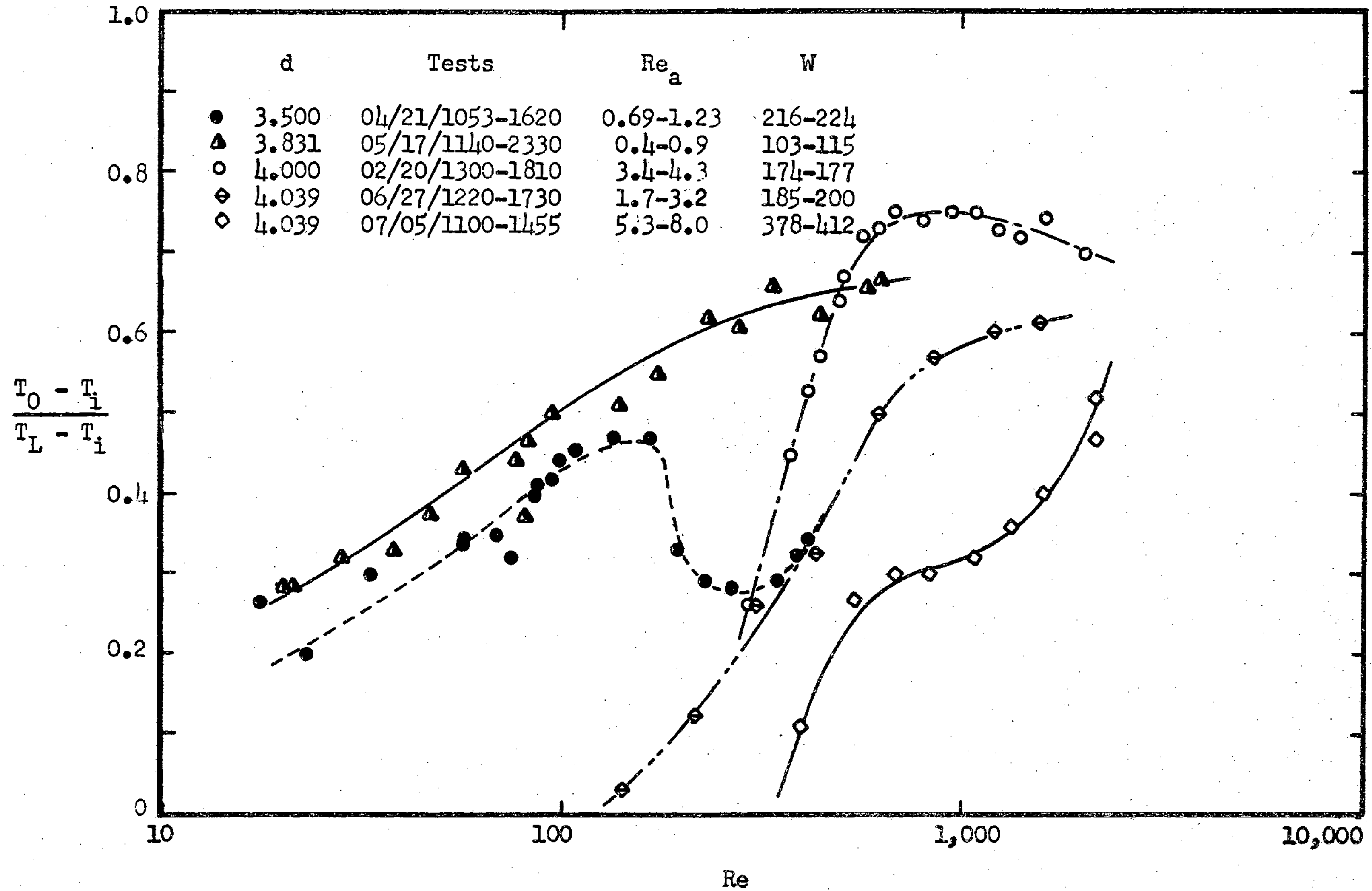


Figure 24. Selected Temperature Jump Ratio Data

The accuracy of the temperature jump ratio and thus the accuracy of the calculated dispersion parameter was primarily dependent upon the accuracy of the exchanger outlet temperature T_L. In the laminar regime substantial radial temperature gradients existed in the exchanger outlet line; the three thermocouples in this line, the locations of which are given in the "Temperature Measurement" section of Chapter IV, in some cases deviated from one another by as much as 5 F. Consequently T_L was calculated from a heat balance in the laminar regime. The measurements in the turbulent regime where the outlet line is essentially isothermal indicate that the heat balance closes only within 10 to 15 percent. Then the denominator of Θ, namely (T_L-T_i), may be in error by as much as 15 percent in the laminar regime; therefore, assuming that T_0 and T_i are not in error, Θ may be 15 percent in error.

There is also some question, which unfortunately cannot be resolved with the present experimental apparatus, as to whether the temperature indicated by the thermocouple just inside the exchanger inlet was the true local bulk fluid temperature. The hottest and coldest regions of the liquid in the exchanger periodically moved past this thermocouple, but it still might not have indicated the true local bulk temperature. This temperature would be expected to be more in error in the laminar regime than in the turbulent regime. There is one indication that it did indicate a true local bulk temperature: when the effect of backmixing was negligible, T_0 was very nearly equal to T_i.

Application of the Dispersion Model to the Present Experimental System

The effect of backmixing on the MTD is here interpreted in terms of the dispersion model. As has already been pointed out in Chapter II the dispersion model of the backmixing phenomena is a one-parameter model (that parameter is α_E). The effective thermal diffusivity (α_E) has to be determined from experimental data by use of theoretical solutions of the dispersion model.

Certain assumptions have to be made in order to obtain analytical solutions of the dispersion model. The major assumptions for the analytical work done here are as follows:

(a) constant effective thermal diffusivity

(b) constant heat transfer coefficient

(c) no axial dispersion in the inlet and outlet lines

With these basic assumptions analytical solutions which are pertinent to obtaining meaningful values of α_E from the experimental data have been obtained in Appendix A for the following special cases:

1. constant wall temperature
2. constant wall heat flux
3. constant wall heat flux with infinite axial conduction in the agitator (i.e. the thermal conductivity of the agitator is assumed infinite).

The closed analytical solutions to the above three special cases are given in Appendix A as equations (A-14, A-27 and A-47), respectively. These equations shall not be given in this chapter because graphical representations of the relationships expressed by these equations are much more instructive than the equations. The functional form of the analytical results for each special case is as follows:

For constant wall temperature.

$$\theta = f(Pe, \beta) \qquad (7\text{-}1)$$

For constant wall heat flux:

$$\Theta = f(Pe) \tag{7-2}$$

For constant wall heat flux with infinite axial conduction in the agitator:

$$\Theta = f(Pe, \beta') \tag{7-3}$$

Here $\beta = \frac{hA}{Wc}$ is the number of transfer units for heat transfer from the exchanger wall, Pe = $\frac{UL}{\alpha_E}$ is the axial dispersion Peclet number and $\beta' = \frac{h_A A_A}{Wc}$ is the number of transfer units for heat transfer to and from the agitator. $\Theta = \frac{T_0 - T_{i}}{T_L - T_{i}}$ is called the temperature jump ratio.

Figure 25 presents the relationships of equations (7-1), (7-2) and (7-3) in graphical form. The solution for the constant wall temperature case is exactly the same as for the case of constant wall heat flux with infinite axial conduction in the agitator with β replaced by β'. The case of constant heat flux can be considered as being a limiting case of the two other cases; it is the same as the solutions for the other two cases when $\beta = 0$ or $\beta' = 0$.

The conditions of this investigation, especially in the laminar regime, are neither constant wall temperature nor constant heat flux. Note, however, from Figure 25 that the dependence of Pe on Θ is the same for the constant wall temperature case and the case for constant heat flux with infinite agitator conduction if β and β' are sufficiently small. If it is assumed that $h = h_A$ then it is shown in Appendix A that $\frac{\beta'}{\beta} \approx 0.64$. Thus if tests are conducted at small values of β, the solution for the constant heat flux case can be used to determine meaningful values of α_E from experimental temperature

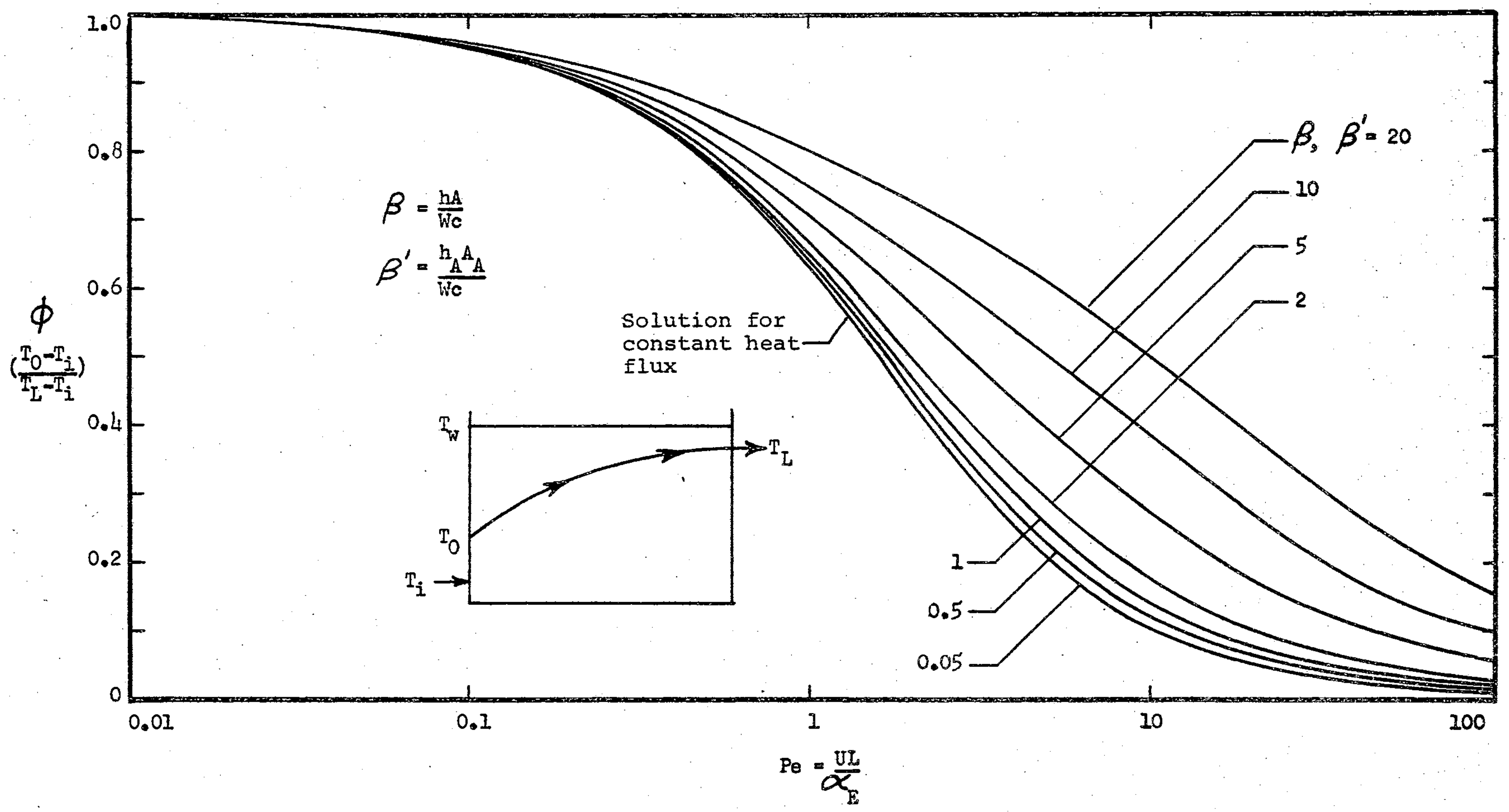


Figure 25. Temperature Jump Ratios from the Dispersion Model for the Cases of (1) Constant Wall Temperature and (2) Constant Wall Heat Flux with Infinite Conduction in the Agitator

jump ratios provided that the assumptions (a), (b) and (c) above are reasonably satisfied.

Unfortunately these assumptions deviate considerably from physical reality in the laminar regime. With respect to assumption (a) of a constant axial dispersion coefficient, the dispersion model has been shown to represent the backmixing phenomena in turbulent flow, particularly for flow through pipes; it has not been shown to represent the backmixing process for laminar flow in agitated systems where the backmixing possibly arises from secondary flows which is possibly the backmixing mechanism for the thin, flat-blade agitator.

Assumption (b) of constant heat transfer coefficient is a very good approximation in the turbulent regime. In the laminar regime it was pointed out in Chapter VI the heat transfer coefficient was generally higher near the center of the exchanger than near the ends of the exchanger and, in particular, it was pointed out that the developing adverse temperature gradient at the inlet results in higher heat transfer coefficients at the inlet than at other axial locations. This high heat transfer coefficient just inside the exchanger inlet causes the temperature immediately inside the exchanger inlet to be higher than it would if the heat transfer coefficient were constant axially. In turn, when Pe is computed from measured values of θ it is less than the true value of Pe; this results in computed values of α_E that are higher than the true values. Thus one would expect that the calculated values of α_E might be larger than the correct values of α_E in the laminar regime.

Correlation of α_E in Terms of the Operating Parameters of the System

α_E was calculated from the experimental temperature jump ratio data from the analytical solution for the case of constant heat flux. The curve of α_E vs. Pe in Figure 25 for the case of constant heat flux was curve-fitted in three portions to get Pe explicitly in terms of . The curve fits are documented in the computer program which is given in Appendix D.

The dispersion parameter α_E was correlated with the operating parameters of the agitated heat exchanger by the method used by Croockewit, Honig and Kramers (14), which is analogous to earlier correlations for axial flow in pipes. $\alpha_E/v_t D_e$ was plotted vs. Re. Correlations for the different blades are presented in Figures 26, 27, 28 and 29. Except for the 3.500 inch diameter blade the correlation brings the data for different axial flow rates together. The results of this correlating method for the various blades are compared in an approximate manner in Figure 30. The data for the 3.500 inch diameter blade and the 3.831 inch diameter blade are sufficiently close together so that they are represented by a single curve in Figure 30 and likewise for the 4.000 inch diameter blade and the 4.039 inch diameter blade. In the laminar regime the effective thermal diffusivity for the two largest clearances is much larger than for the two smallest clearances. This may be a result of the "simple-one parameter dispersion model" not representing the dispersion phenomena in the laminar regime, or it may be because the heat transfer coefficient was so much higher near the inlet than near the outlet for the large clearances or a combination of the two.

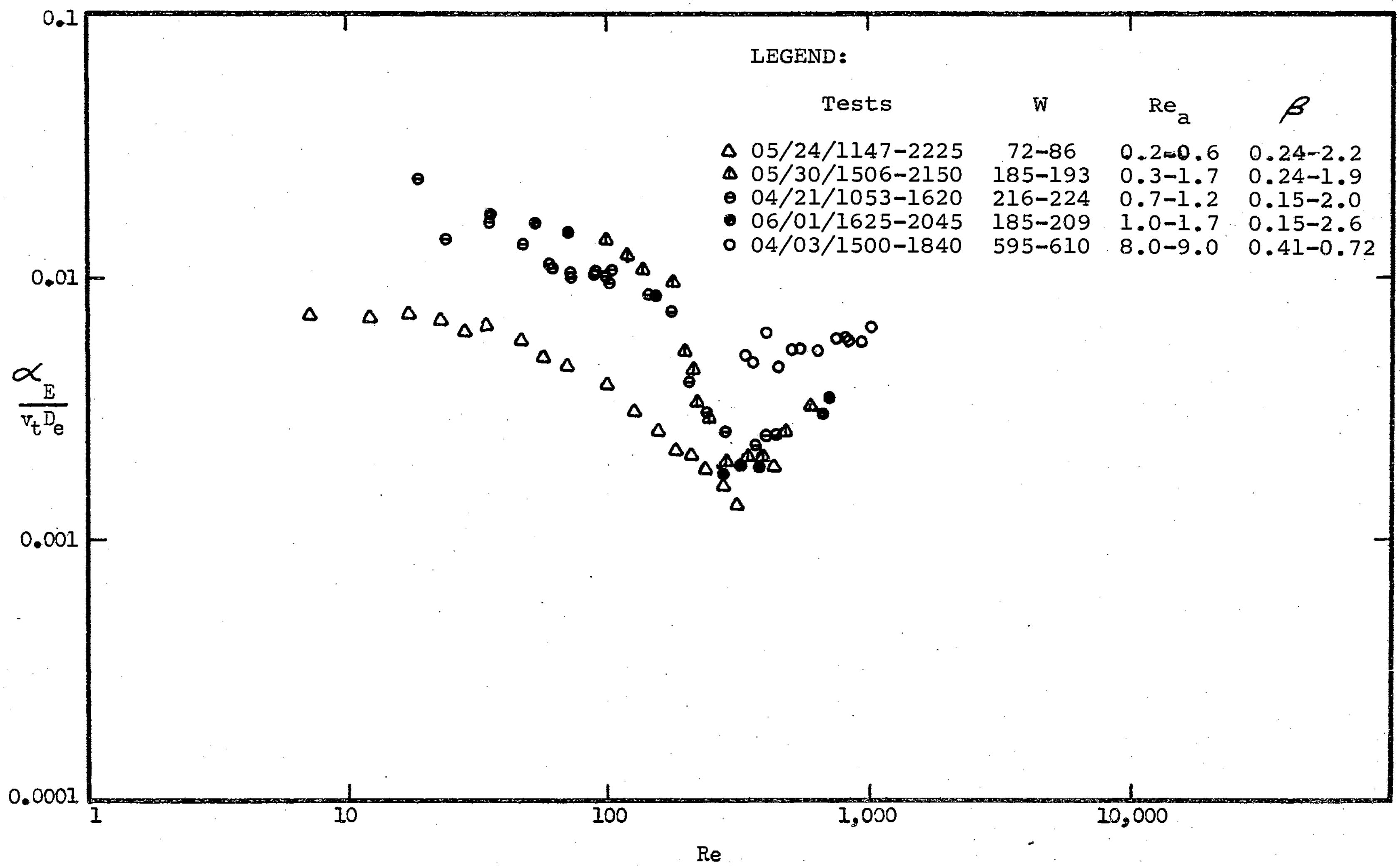


Figure 26. Axial Dispersion Correlation for the 3.500 inch Diameter Blade

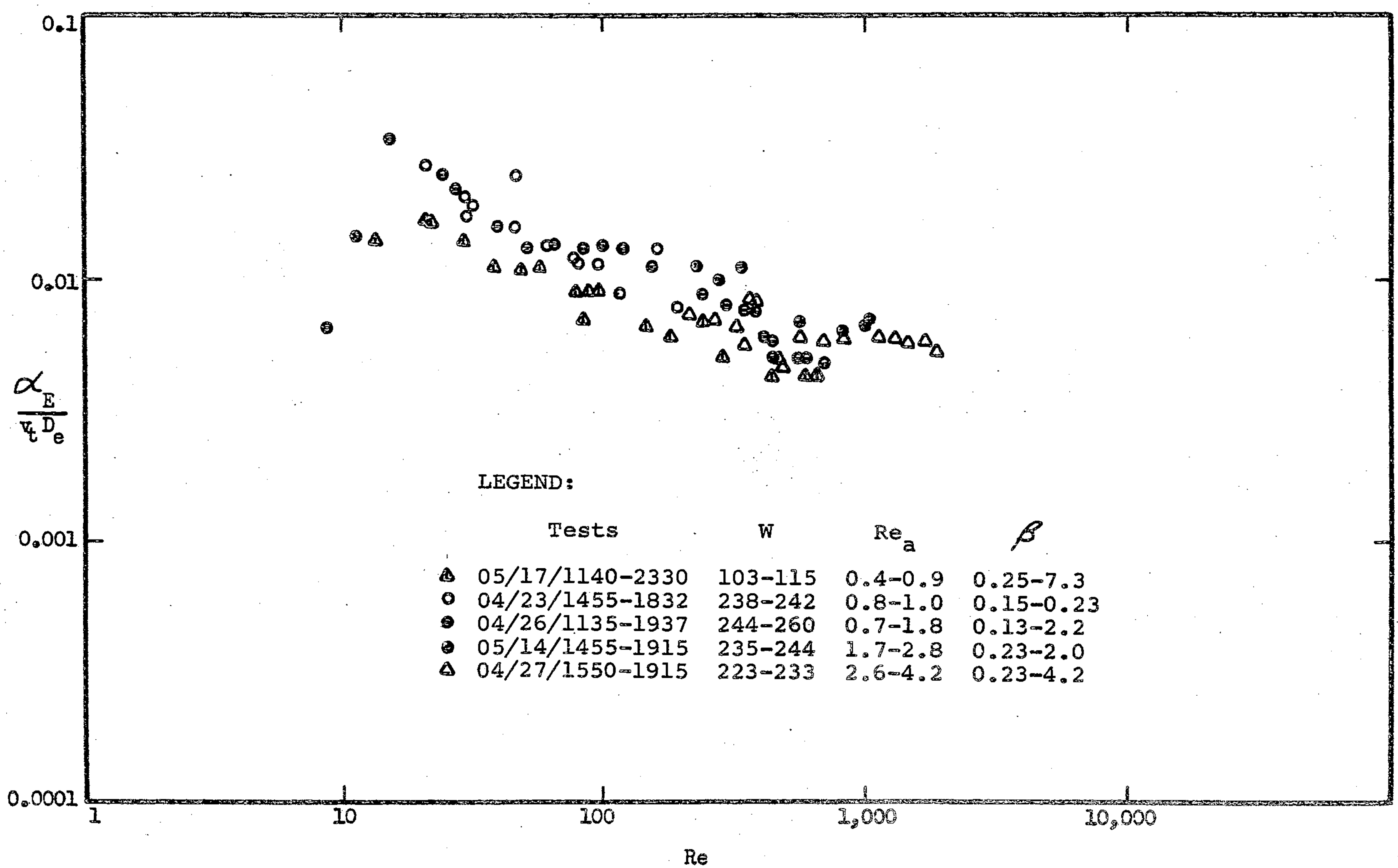


Figure 27. Axial Dispersion Correlation for the 3.831 inch Diameter Blade

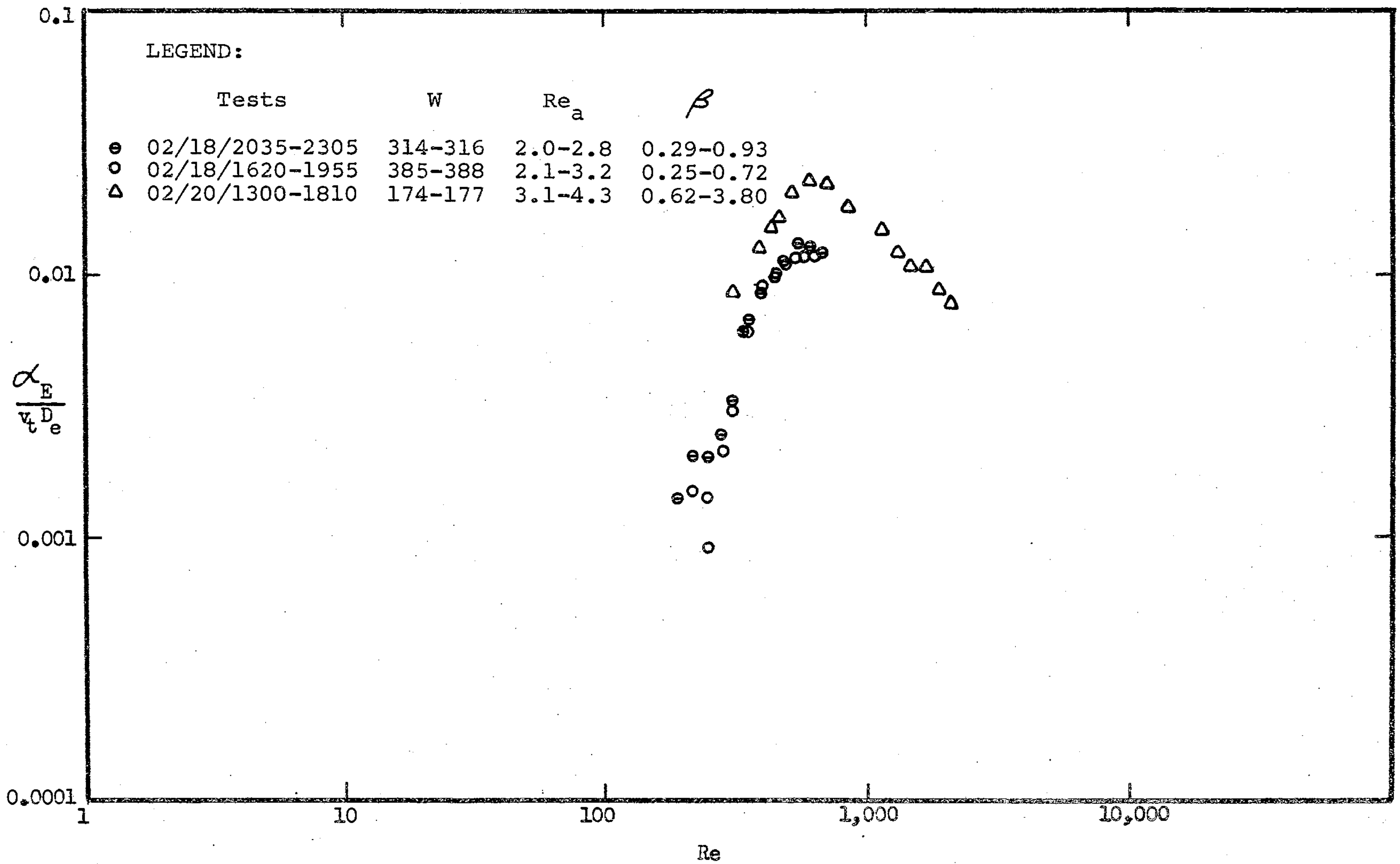


Figure 28. Axial Dispersion Correlation for the 4.000 inch Diameter Blade

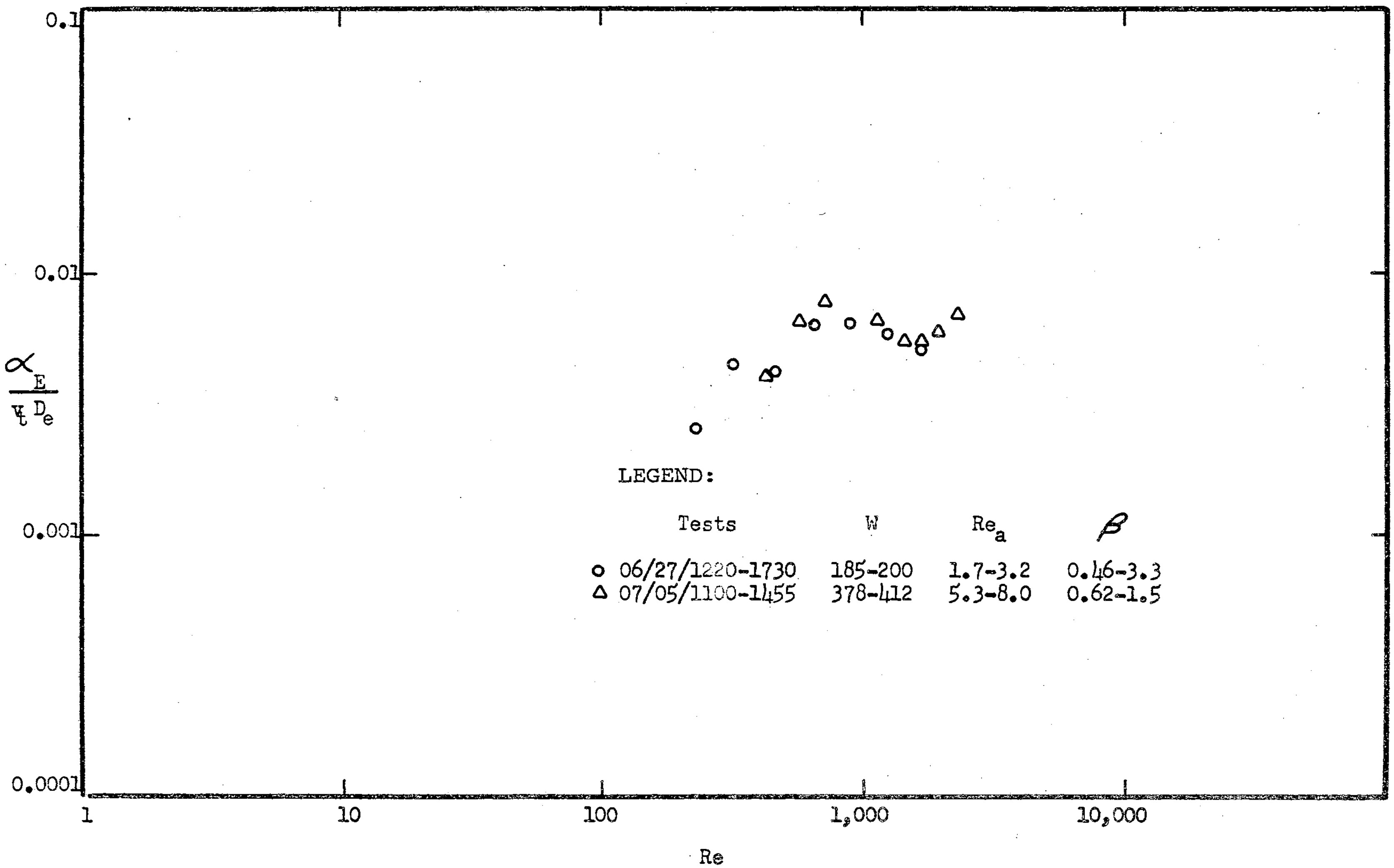


Figure 29. Axial Dispersion Correlation for the 4.039 inch Diameter Blade

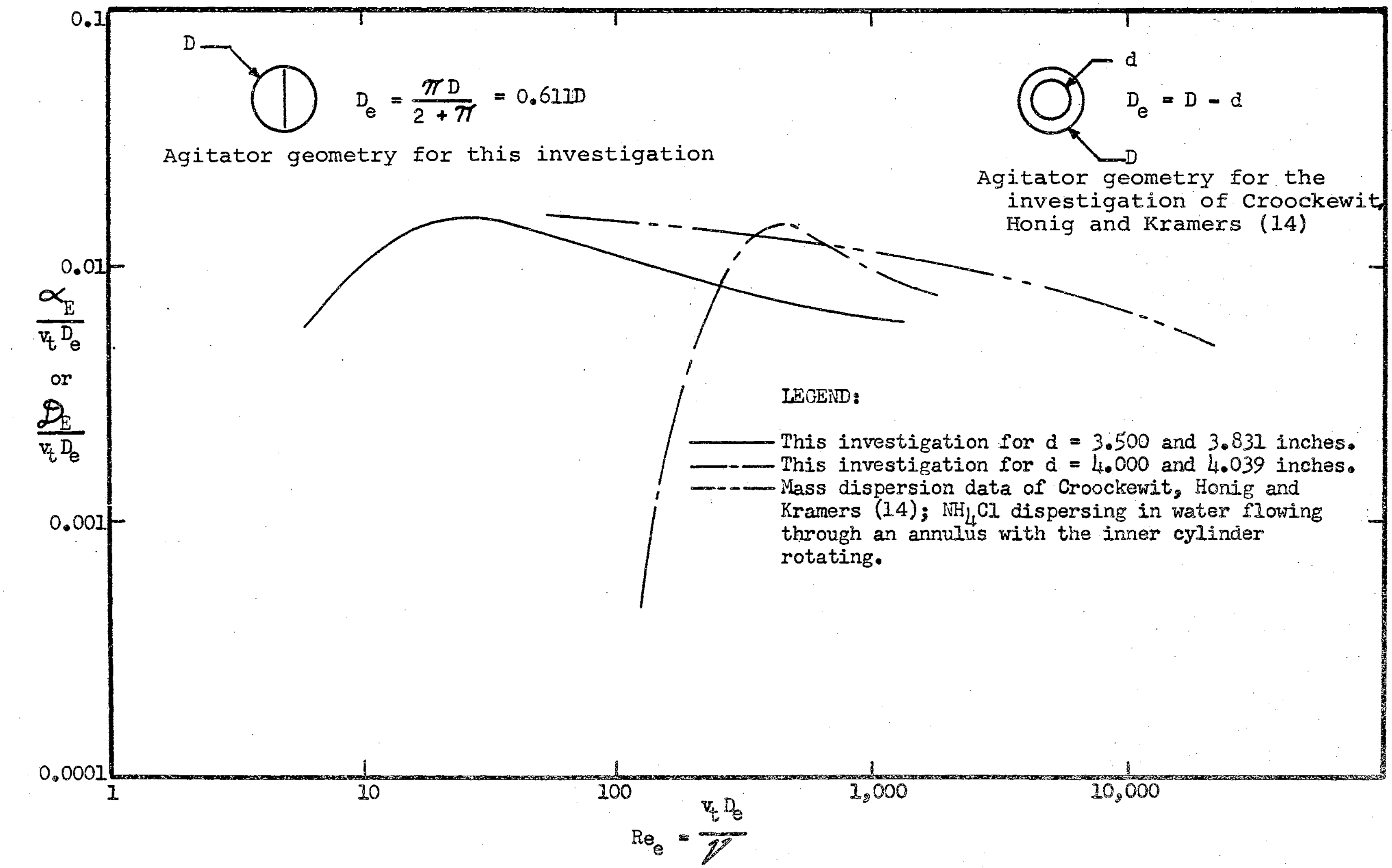


Figure 30. Axial Dispersion Correlation

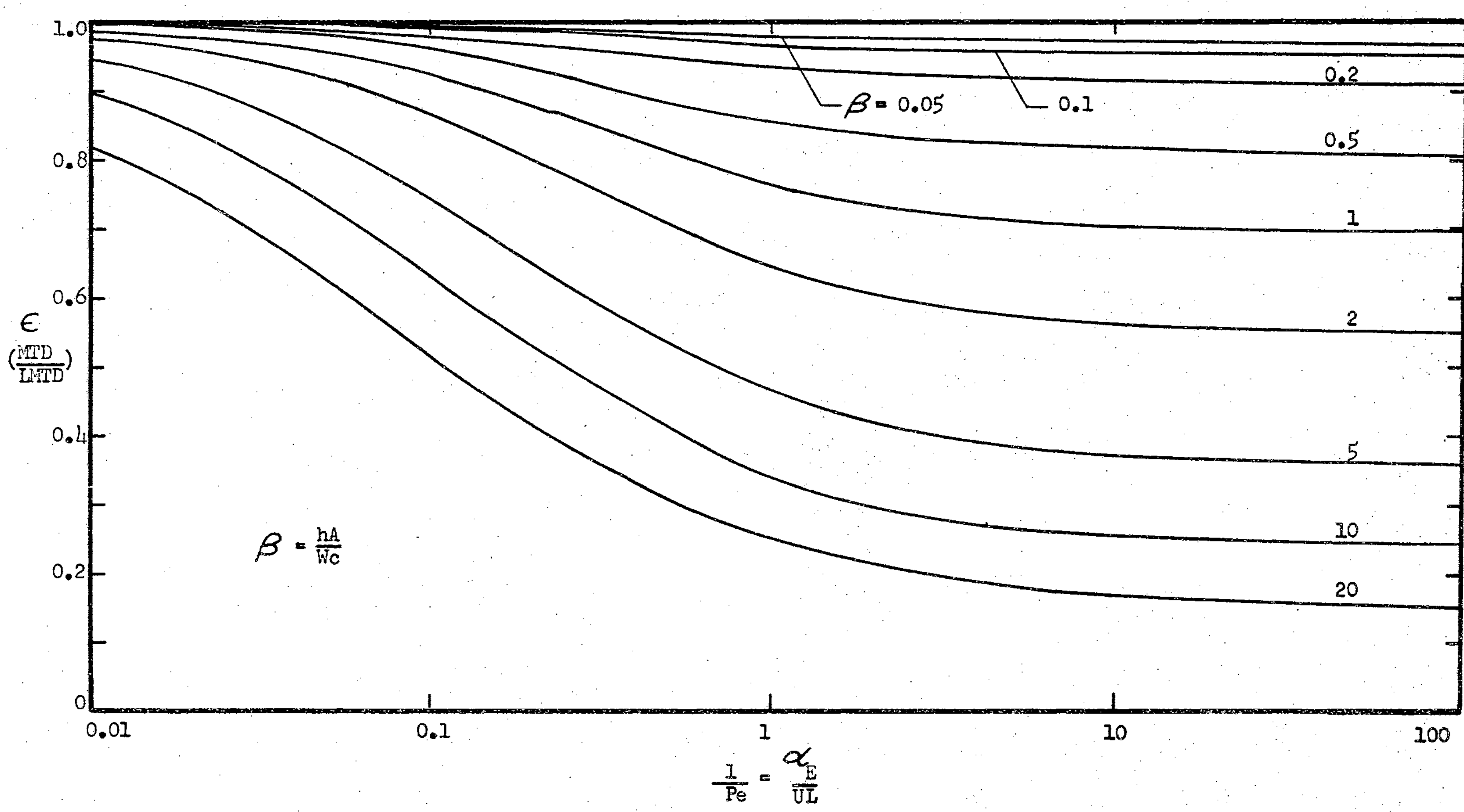


Figure 31. The Effect of Axial Dispersion of Heat on the MTD from the Dispersion Model

The data compare reasonably well in the turbulent regime and they also compare reasonably well with data for axial dispersion of mass in an annulus with the inner cylinder rotating. The correlation of Figure 30 uses an equivalent flow channel diameter (D_e) in both the dimensionless dispersion parameter and also in the Reynolds number.

This correlation indicates that the dispersion model will probably adequately represent the dispersion phenomena for design of mechanically-agitated equipment in the turbulent regime. It also indicates that the dispersion model may not be adequate to represent the dispersion phenomena in the laminar regime.

Design Method for Predicting the Effect of Backmixing on the MTD

The presentation of the results of the dispersion model in Figure 25 is necessary in order to obtain α_ϵ from values of Θ obtained from measurements but this chart cannot be used for design purposes. For design purposes one fixes exterior temperatures and not T_o. The dispersion model for the constant wall temperature case can be recast in terms of the ratio of the true mean temperature difference (MTD) to the logarithmic mean temperature difference (LMTD). The mathematics of this operation are given in Appendix A. In Figure 30 the ratio of MTD to LMTD ( ) is plotted vs. 1/Pe with   as a parameter. This plot can be used for design purposes if correlations are available for heat transfer coefficients and the effective thermal diffusivity.

The assumption of constant wall temperature will probably represent physical reality well in most design cases because the temperature change of the process stream is generally much greater than the temperature change of the cooling or heating medium.

Once the MTD has been determined the area of the heat exchanger can be determined from the familiar expression:

$$A = Q/[(h)(MTD)] \qquad (7\text{-}4)$$

The heat transfer coefficient for agitated heated exchangers with flat blade agitators could probably be determined with sufficient accuracy for most design purposes with the results of this investigation if L/D for the exchanger in question were longer than L/D of the test exchanger used here.

The design information discussed here is strictly applicable only if the exchanger wall temperature is constant and if the heat transfer coefficient is constant; however, it will find practical application in many cases when these conditions are not strictly met simply because it will be the only or the best design information available.

CHAPTER VIII

CONCLUSIONS, COMMENTS AND RECOMMENDATIONS

Agitator Power Requirements

(1) The agitator power requirements for the knife-edged flat blade tested here have been correlated by plotting P_{bL} vs. Re with C/D as a parameter. This correlation appears to be completely general for this agitator; it can probably be used to predict agitator bulk power requirements for flat blades with non-zero thickness near the vessel wall.

(2) The power consumption for the knife-edged flat blade agrees with power consumption for anchor agitators within 30 percent when compared on a plot of P_{tL} vs. Re with C/D as a parameter. This agreement indicates that anchor arm width has little effect on agitator power requirements over a wide range of arm widths, if the free surface in the case of the anchor tests does not affect the agitator power consumption significantly.

(3) Additional work is needed to determine the effect of the blade thickness on agitator power requirements.

Heat Transfer Coefficients

(1) In the turbulent regime neither agitator geometry nor clearance has a significant effect on heat transfer over the range tested.

(2) For large clearances in the transition regime a small change in Re

effects a very large change in heat transfer. For small clearances the change is much smaller.

(3) For large clearances the heat transfer for anchor agitators in the laminar regime is up to seven times higher than for the flat blade at the same Re and the same C/D. This indicates that agitator geometry may have a considerable effect on heat transfer in the laminar regime.

(4) In the laminar regime small clearances give much higher (up to seven times higher for this investigation) heat transfer than do large clearances.

(5) Additional work is needed in the laminar regime to determine the proper correlating method in this regime. In particular tests should be conducted with a viscous fluid which has thermal properties widely different from the oils previously used. The effect of agitator geometry should also be studied in the creeping flow regime.

The Effect of Backmixing on the MTD

(1) The solutions of the dispersion model for the cases of constant wall temperature and constant heat flux have been put into convenient form for calculating dispersion parameters from experimental temperature measurements.

(2) For the case of constant wall temperature the solution of the dispersion model has been put in convenient form for use in heat exchanger design.

(3) The dispersion data of this investigation were correlated using a previously suggested correlation of plotting $\frac{\alpha_E}{v_E D_e}$ vs. Re. This

method correlated both the effect of axial flow and clearance in the highly turbulent regime, and it adequately correlated the effect of axial flow; but it failed to correlate the effect of clearance in the laminar regime.

(4) The dispersion model probably adequately represents the dispersion phenomena in the turbulent regime but it may not adequately represent the dispersion phenomena in the laminar regime.

(5) Additional work is urgently needed to develop methods to describe the axial dispersion phenomena in the laminar regime.

Recommendations for Obtaining More Accurate and Meaningful Data

There are certain improvements to the experimental apparatus which would give more accurate data. The accuracy of the heat transfer coefficients in the laminar regime could be improved by doing any or all of the following: make the exchanger longer, decrease the exchanger wall thickness and/or construct the exchanger of a material with a lower thermal conductivity than aluminum. The heat balance could be improved by either or both of the following: thoroughly mix the outlet fluid before measuring its temperature and/or measure the flow rate through the exchanger by a weighing technique.

Temperature measurements at other radial locations just inside the exchanger inlet would be helpful to determine if the temperature as obtained here is truly the fluid bulk temperature at that location.

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NOMENCLATURE

Nomenclature for Main Body of Thesis

a	- parameter defined by equation (A-10)
A	- inside surface area of heat exchanger, sq. ft.
A_A	- surface area of agitator, sq. ft.
A_F	- cross-sectional area of flow channel, sq. ft.
A_W	- cross-sectional area of exchanger wall, sq. ft.
C	- clearance between agitator and vessel wall, ft.
c	- specific heat at constant pressure, B.t.u./$lb._m$ F.
d	- diameter of agitator, ft.
D	- diameter of vessel, ft.
D_e	- equivalent flow channel diameter, ft.
d_s	- diameter of inner shaft, ft.
$\mathcal{D}_E$	- effective diffusivity of mass in the dispersion model, sq. ft./hr.
g	- parameter defined by equation (A-14)
g_c	- conversion constant, 32.2 $lb._m$-ft./$lb._f$sq. sec.
h	- heat transfer coefficient, B.t.u./hr. sq. ft. F
h	- pitch of helix on auger or helical ribbon, ft.
k	- thermal conductivity, B.t.u./hr. ft. F.
k_E	- effective thermal conductivity in the dispersion model, B.t.u./hr.ft. F.
L	- length of agitator, ft.
LMTD	- logarithmic mean temperature difference, F.

MTD - mean temperature difference, F.

n_b - number of blades on agitator

N - agitator speed, rev/hr.

Nu - hD/k, Nusselt No.

p - power, ft.-$lb._f$/sec.

p_b - power consumed in the bulk of the fluid, ft.-$lb._f$/sec.

p_c - power consumed in the clearance, ft.-$lb._f$/sec.

p_t - $p_b + p_c$, total power consumed by straight agitator, ft.-$lb._f$/sec.

P - perimeter of flow channel, ft.

P - conventional power number, $p_t g_c/\rho N^3 d^5$

P_{bL} - $p_b g_c/\rho N^3 d^4 L$

P_{cL} - $p_c g_c/\rho N^3 d^4 L$

P_{tL} - $p_t g_c/\rho N^3 d^4 L$

Pe - $\frac{UL}{\alpha_E}$, Peclet number for axial dispersion

Pr - $\frac{\mu c}{k}$, Prandtl number

q_F - heat flux to the fluid from the inner heat exchanger wall, Btu/hr. sq. ft.

q_H - heat flux from the electrical wall heating element, Btu/hr. sq. ft.

Re - $Nd^2\rho/\mu$, rotational Reynolds number

Re_a - $\frac{UD}{\nu}$, axial flow Reynolds number

t - circumferential thickness of agitator nearest vessel wall, ft.

T - temperature, F.

U - axial flow velocity, ft./hr.

u - overall heat transfer coefficient, Btu/hr. sq. ft. F.

v_t - blade tip velocity, ft./hr.

W - axial flow rate, lb. m./hr.

Y - z/L

z - axial dimension, ft.

W_a - width of agitator arm, ft.

W_r - width of helical ribbon, ft.

Greek Letters

α - constant in equation (2-10)

α - proportionality constant

β - exponent on Pr in equation (2-10)

β - $\frac{hA}{Wc}$, number of transfer units for the heat exchanger

β' - $\frac{h_A A_A}{Wc}$, number of transfer units for the agitator

θ - time between successive scrapings (contact time), hr.

θ - $\frac{T_o - T_i}{T_L - T_i}$, temperature jump ratio

μ - kinematic viscosity, lb.m./hr.ft.

ν - absolute viscosity, sq. ft./hr.

μ - kinematic viscosity, lb.m./hr.ft.

ρ - liquid density, lb.m./cu.ft.

ϕ - ratio of bulk to surface viscosity

ϕ - $\frac{T_b - T_w}{T_i - T_w}$, parameter defined by equation (A-3)

ϵ - $\frac{MTD}{LMTD}$, ratio of the mean temperature difference to the logarithmic mean temperature difference

Subscripts

0 - at $z = 0$ just inside the exchanger inlet

A - agitator

b - bulk liquid

E - signifies effective thermal diffusivity of heat or mass

F - fluid

H - heater

i - exchanger inlet

L - at $z = L$, the exchanger outlet

w - exchanger wall

Nomenclature for Data Reduction Computer Programs

Input Data

AMPS - electrical current through the exchanger wall heating element, amperes

CIS - cycle timer reading at the start of a timing period

CIF - cycle timer reading at the end of a timing period

NW - the number (or numbers if NW is two or three digits) of weight or weights on the dynamometer lever arm

POT - setting of the potentiometer speed control for the D.C. motor which turned the agitator

TI - time interval between the start and end of a cycle timer timing period, seconds

TFLOW - time for the test liquid to rise six inches in the reservoir, seconds

TMI - month in which data were taken

TMD - day in which data were taken

TMZ - time of day in minutes from 12 p.m. in which data were taken

TWMV - 1 x 11 array of the eleven wall temperatures, millivolts

TEOLMV - temperature in the exchanger outlet line, millivolts

TEILMV - temperature in the exchanger inlet line, millivolts

TEIMV - temperature just inside the exchanger at the inlet end, millivolts

TEOMV - temperature just inside the exchanger at the outlet end, millivolts

VOLTS - voltage drop across the exchanger wall heating element, volts

XLA - distance from the side of the weight nearest the D.C. agitator motor to the frame of the agitator motor, inches

Calculated and Program Variables*

AGRPM - N, rev./min.

BETA - hA/Wc, number of transfer units for the heat exchanger

BR - Brinkman number, ratio of power input to the test liquid by the agitator to power input to the test liquid through the heat exchanger wall

C - c, heat capacity of the test fluid at the average film temperature

DA - d, ft.

DELTE - $T_L - T_i$

DELTF - $(T_W - T_b)_{z = 14}$

DENB - ρ, test fluid density at $(T_b)_{z = 14}$

HP - net horsepower the agitator imparted to the test liquid

HC - h, experimental heat transfer coefficient at z = 14 corrected for axial wall heat conduction

HX - experimental heat transfer coefficient uncorrected for axial wall heat conduction

I - loop counter

L - loop counter

M - index to identify agitator diameter

P - inside circumference of the test heat exchanger, ft.

PE - $\frac{VL}{\alpha_E}$, Pe

PEDA - $\frac{v_t \alpha_E}{D_e}$

PN - P_{bL}

Q - electrical heat input to the wall heating element, Btu/hr.

Q - net heat input to the fluid through the exchanger wall, Btu/hr.

*Not all these variables will be identified; only those essential to easily comprehending the calculation procedures will be identified. Where applicable these variables shall be identified in terms of the nomenclature of the main body of the thesis.

QAGIT – power input to the test liquid by the agitator, Btu./hr.

QL – heat loss from the heat exchanger to the laboratory environment. Btu./hr.

QOAR – q_F/q_H (see equation (E-2))

QOA – average heat flux from the inside exchanger wall to the test fluid, Btu./hr.sq.ft.

REA – Re_a

RER – π x Re, Reynolds number based on blade tip velocity

RERC – Re

T – total torque produced by the agitator, in.lb.f.

T – (T–TF) net torque produced by the agitator acting on the test liquid, in. lb. f.

TEAVG – $(T_b)_z = 14$

TEI – T_O

TEIL – T_i

TEO – T_L

TEOL – T_L

TF – torque produced by the agitator due to bearing friction, in. lb. f.

TFILM $\left(\frac{T_w + T_b}{2}\right)_{z=14}$, average film temperature, F

TRATIO – $\frac{T_o - T_i}{T_L - T_i}$, temperature jump ratio

TWAVG – $\sum_{N=1}^{11} TW(N)/11$, average wall temperature, F

TWM – $\frac{TW(4) + TW(5)}{2}$

TW(N) – 1 x 11 array of the eleven wall temperatures, F

VAT – v_t

VFPM – axial flow velocity, ft./min.

VISB – μ, test fluid kinematic viscosity at $(T_b)_z = 14$

W1 – weight of dynamometer weight number 1, lb.m.

WLBH – W

XJVISC — $\frac{Nu}{Pr^{1/3}} \phi^{0.18}$

XK — k, test fluid thermal conductivity at the average film temperature

XNU — $\frac{hd}{k}$, Nu

XL — length of the test heat exchanger, ft.

APPENDIX A

ANALYTICAL SOLUTIONS OF THE DISPERSION MODEL

There were two objectives of the following mathematical work: The first was to obtain dispersion parameters from the experimental data. The second was to develop a method for conveniently predicting the MTD in an exchanger with axial dispersion.

The solutions obtained were the minimum necessary to achieve these objectives. Considerably more theoretical work could have been done. Much numerical differential equation solving could have been done. In particular numerical methods could have been used to solve the dispersion model with an axial variation of heat transfer coefficient. It was decided, however, to use the analytical solutions to their fullest extent here and then let future researchers use this work to guide their work, which may well include numerical work.

Analytical solutions for the dispersion model were obtained for the following special cases:

(1) constant wall temperature with no axial dispersion in the inlet and outlet lines. This solution was originally given by Danckwerts (15). It is recast in heat transfer terminology here. Wehner and Wilhelm (49) have shown that the axial dispersion in the inlet and outlet lines does not affect the temperature distribution in the exchanger.

(2) constant wall heat flux with no dispersion in the inlet and outlet

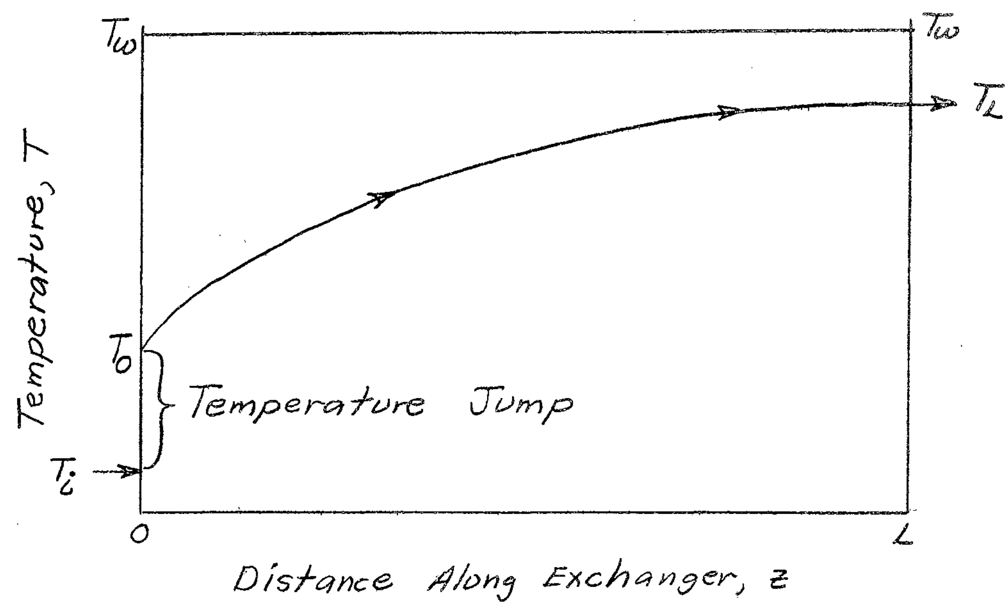
lines.

(3) constant wall heat flux with no dispersion in the inlet and outlet lines and with infinite axial conduction in the agitator (i.e. the thermal conductivity of the agitator is infinite).

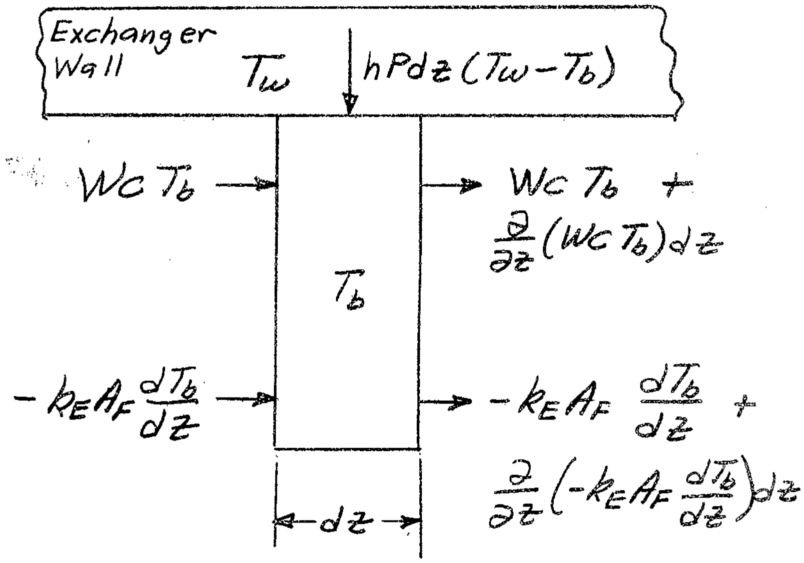
Constant Wall Temperature with Axial Dispersion
In the Inlet and Outlet Lines

Development of Basic Differential Equations

The sketch below shows qualitatively the temperature distribution in the exchanger.



The governing differential equation is developing by making a heat balance on a differential element of the heat exchanger. The following sketch gives the heat streams associated with an axial differential element of the exchanger.



The differential element is at steady state, therefore:

Heat In - Heat Out = 0 (A-1)

This heat balance then becomes

$$k_E A_F \frac{d^2 T_b}{dz^2} - Wc\frac{dT_b}{dz} - hP(T_b - T_w) \quad \text{(A-2)}$$

because T_b is the only dependent variable.

Let

$$\phi = \frac{T_b - T_w}{T_i - T_w} \quad \text{(A-3)}$$

$$Y = z/L \quad \text{(A-4)}$$

Then equation (A-2) becomes

$$\frac{k_E A_F}{WcL}\frac{d^2\phi}{dY^2} - \frac{d\phi}{dY} - \frac{hPL}{Wc}\phi = 0 \quad \text{(A-5)}$$

Now

$$\frac{k_E A_F}{WcL} = \frac{1}{\left(\frac{W}{\rho A_F}\right)\frac{L}{\left(\frac{k_E}{\rho c}\right)}} = \frac{1}{\frac{UL}{\alpha_E}} = \frac{1}{Pe} \qquad \text{(A-6)}$$

Let

$$\beta = \frac{hPL}{Wc} = \frac{hA}{Wc} \qquad \text{(A-7)}$$

Then equation (A-5) becomes

$$\frac{1}{Pe}\frac{d^2\phi}{dY^2} - \frac{d\phi}{dY} - \beta\phi = 0 \qquad \text{(A-8)}$$

General Solution

The general solution to equation (A-8) is:

$$\phi = N_1 e^{\frac{Pe}{2}(1+a)Y} + N_2 e^{\frac{Pe}{2}(1-a)Y} \qquad \text{(A-9)}$$

where

$$a = \sqrt{1 + \frac{4\beta}{Pe}} \qquad \text{(A-10)}$$

Boundary Conditions

The two necessary boundary conditions are obtained by making heat balances at Y = 0 and Y = 1. For the case considered here of no dispersion in the inlet and outlet line these two boundary conditions were first given by Danckwerts (15). The two boundary conditions are as follows:

$$\frac{1}{Pe}\left[\frac{d\phi}{dY}\right]_{Y=0} = \phi_0 - 1 \qquad \text{(A-11)}$$

$$\left[\frac{d\phi}{dY}\right]_{Y=L} = 0 \qquad \text{(A-12)}$$

Particular Solution

Application of these boundary conditions to equation (A-9) gives the following particular solution:

$$\phi = g e^{\frac{Pe}{2}Y}\left[(1+a)e^{\frac{aPe}{2}(1-Y)} - (1-a)e^{-\frac{aPe}{2}(1-Y)}\right] \qquad \text{(A-13)}$$

where

$$g = \frac{2}{(1+a)^2 e^{\frac{aPe}{2}} - (1-a^2)e^{-\frac{aPe}{2}}} \qquad \text{(A-14)}$$

Rearranging Particular Solution to Have $\frac{T_O - T_i}{T_L - T_i}$ as Dependent Variable

The theoretical development in the preceding section was for the condition of constant wall temperature. The experimental wall temperature is not constant. Also because of axial conduction in the exchanger wall the wall temperature is not linear in the axial direction as would be obtained if the heat flux to the test fluid and the heat transfer coefficient were constant. Due to conduction from the exchanger wall to the endplates the axial variation of exchanger wall temperature cannot be described analytically. The approach, which will be used here to develop an analytical method for determining α_E from experimental data, is to eliminate T_W from the analytical solutions for the cases of constant wall temperature and constant heat flux and show that when $\beta = 0$ the solutions for these two limiting cases coincide. This limiting solution will be used to obtain α_E from experimental data.

With this in mind let us rearrange the particular solution to contain temperatures which are readily determined experimentally. The particular solution given as equation (A-13) can be rearranged as follows:

$$\frac{T_0 - T_i}{T_L - T_i} = \frac{\phi_0 - 1}{\phi_L - 1} = \frac{g\left[(1+a)e^{a\frac{Pe}{2}} - (1-a)e^{-a\frac{Pe}{2}}\right] - 1}{2ag\,e^{Pe/2} - 1} \qquad \text{(A-14)}$$

T_i, T_0 and T_L are all readily measured. From (A-14), $(T_0-T_i)/(T_L-T_i)$ is only a function of Pe and β. This relationship is presented graphically in Figure 25.

Ratio of MTD to LMTD

The ratio of MTD to LMTD (MTD/LMTD $=\epsilon$) has been used extensively for design of heat exchangers. It has been selected as a design parameter here. Other dimensionless parameters involving the same temperatures as ϵ could have been used. It was felt that ϵ would have more physical meaning to a designer than other parameters which could have been used.

The LMTD can be expressed as follows:

$$LMTD = \frac{-(T_i - T_w)(\phi_L - 1)}{\ln(\phi_L)} \qquad \text{(A-15)}$$

The MTD can be calculated by integrating $(T_w - T_b)$ over the length of the exchanger

$$MTD = \frac{1}{L}\int_0^L (T_w - T_b)\,dz = -\int_0^1 \phi(T_i - T_w)\,dY \qquad \text{(A-16)}$$

Substituting for ϕ from equation (A-13) equation (A-16) becomes

$$MTD = -(T_i - T_w)\int_0^1 g\left[(1+a)e^{\frac{Pe}{2}(a - aY + Y)} - (1-a)e^{\frac{Pe}{2}(-a + aY + Y)}\right]dY \qquad \text{(A-17)}$$

$$MTD = \frac{-2q(T_i - T_w)}{Pe(1-a^2)}\left[-(1+a)^2 e^{\frac{Pe\,a}{2}} + (1-a)^2 e^{-\frac{Pe\,a}{2}} + 4a e^{\frac{Pe}{2}}\right] \quad \text{(A-18)}$$

After simplifying we obtain

$$MTD = \frac{(T_i - T_w)(\phi_L - 1)}{\beta} \quad \text{(A-18)}$$

Then

$$\epsilon = \frac{MTD}{LMTD} = -\frac{Ln(\phi_L)}{\beta} \quad \text{(A-19)}$$

Thus ϵ is only a function of Pe and β. This relationship has been plotted in Figure 31.

All the theoretical work here has been done with T_w and h. The mathematical development is exactly the same if T_w is replaced by T_c and h with the overall heat transfer coefficient. Thus Figure 30 can be used for design purposes, using T_w in conjunction with h or T_c in conjunction with u.

Constant Heat Flux With No Dispersion in the Inlet and Outlet Lines

Development Of Basic Differential Equation

For this case the basic differential equation, which is analogous to equation (A-2) is as follows:

$$k_E A_F \frac{d^2 T_b}{dz^2} - wc\frac{dT_b}{dz} + q/L = 0 \quad \text{(A-20)}$$

Let

$$\theta = T_b/T_i \quad \text{(A-21)}$$

$$Q/W c T_i = R \qquad \text{(A-22)}$$

then equation (A-20) becomes

$$\frac{1}{Pe}\frac{d^2\theta}{dY^2} - \frac{d\theta}{dY} + R = 0 \qquad \text{(A-23)}$$

General Solution

The general solution to equation (A-22) is as follows:

$$\theta = N_3 + \frac{N_4}{Pe} e^{PeY} + RY \qquad \text{(A-23)}$$

Boundary Conditions

The two necessary boundary conditions are analogous to those for the constant wall temperature case; thus, with ϕ replaced by θ they are given as equations (A-11) and (A-12).

Particular Solution

Application of these boundary conditions to equation (A-23) gives the following particular solution

$$\theta = \frac{R}{Pe} + 1 + \frac{R}{Pe} e^{Pe(Y-1)} + RY \qquad \text{(A-24)}$$

Rearranging Particular Solution to Have $\frac{T_o - T_i}{T_L - T_i}$ as Dependent Variable

The following relationship is obtained by evaluating equation (A-24) at z = L.

$$\theta_o = \frac{R}{Pe}(1 - e^{-Pe}) + 1 \qquad \text{(A-25)}$$

but

$$R = Q/W c T_i = (T_L - T_i)/T_i \qquad \text{(A-26)}$$

Thus equation (A-25) can be rearranged as follows:

$$\frac{T_o - T_i}{T_L - T_i} = \frac{1}{Pe}\left[1 - e^{-Pe}\right] \qquad \text{(A-27)}$$

Note that $\frac{T_o - T_i}{T_L - T_i}$ is only a function of Pe; whereas, for the constant wall temperature case $\frac{T_o - T_i}{T_L - T_i}$ is a function of both Pe and β. The relationship of equation (A-27) is presented graphically in Figure 25. The relationship between $\frac{T_o - T_i}{T_L - T_i}$ and Pe for the case of constant heat flux is exactly the same as the relationship between $\frac{T_o - T_i}{T_L - T_i}$ and Pe for the constant wall temperature case with $\beta = 0$. The experimental conditions of this investigation are neither constant heat flux nor constant wall temperature. Figure 25 indicates that testing should be conducted with small values of β in order for the experimentally determined values of α_E to be physically meaningful.

Constant Heat Flux with Infinite Conduction

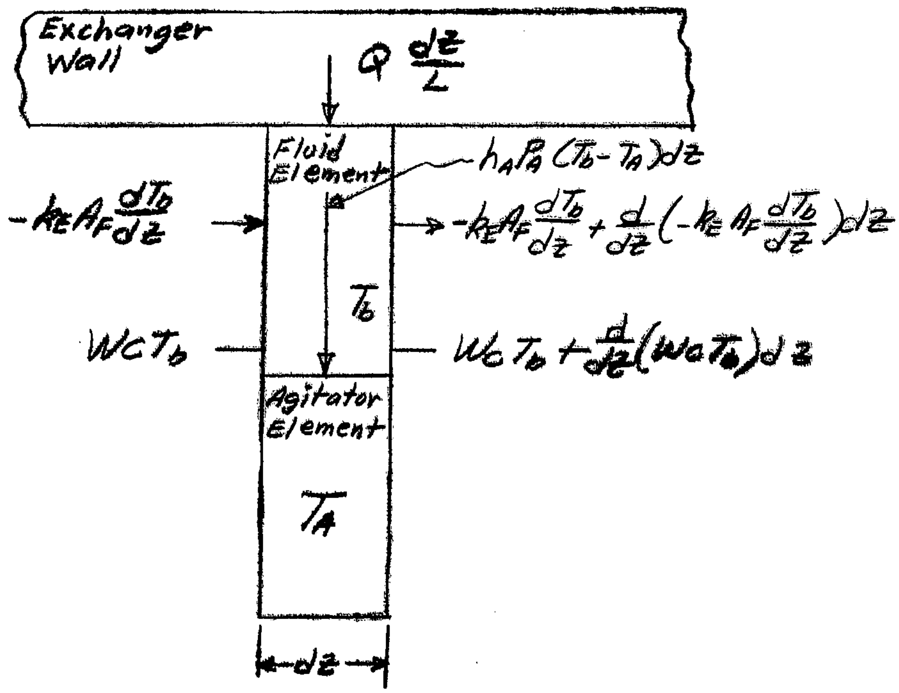
in the Agitator and No Dispersion

in the Inlet and Outlet Lines

Development of Basic Differential Equation

With infinite conduction in the agitator (i.e. k_A is infinite) the temperature of the agitator is constant throughout.

The governing differential equation is developed by making a heat balance on a differential element of the heat exchanger. The following sketch gives the heat streams associated with an axial differential element of the exchanger.



A steady-state heat balance on the differential fluid element yields the following differential equation:

$$k_E A_F \frac{d^2 T_b}{dz^2} - Wc\frac{dT_b}{dz} + \frac{Q}{L} - h_A P_A (T_b - T_A) = 0 \qquad \text{(A-28)}$$

Let

$$\phi = T/T_i \qquad \text{(A-29)}$$

$$Y = z/L \qquad \text{(A-30)}$$

$$\beta' = \frac{h_A P_A L}{Wc} = \frac{h_A A_A}{Wc} \qquad \text{(A-31)}$$

$$R = Q/WcT_i \qquad \text{(A-32)}$$

then equation (A-28) becomes

$$\frac{1}{Pe}\frac{d^2\phi}{dY^2} - \frac{d\phi}{dY} - \beta'\left(\phi - \phi_A - \frac{R}{\beta_A}\right) = 0 \qquad \text{(A-33)}$$

Let

$$\psi = \Phi - \Phi_A - R/\beta_A \qquad \text{(A-34)}$$

then equation (A-33) becomes

$$\frac{1}{Pe}\frac{d^2\psi}{dY^2} - \frac{d\psi}{dY} - \beta'\psi \qquad \text{(A-35)}$$

General Solution

The general solution to equation (A-35) is as follows:

$$\psi = N_5 e^{\frac{Pe}{2}(1+a')Y} + N_6 e^{\frac{Pe}{2}(1-a')Y} \qquad \text{(A-36)}$$

where

$$a' = \sqrt{1 + \frac{4\beta'}{Pe}} \qquad \text{(A-37)}$$

Boundary Conditions

The two necessary boundary conditions are analogous to those for the constant wall temperature case which are given as equations (A-11) and (A-12). These boundary conditions in terms of ψ are as follows:

$$\frac{1}{Pe}\left[\frac{d\psi}{dY}\right]_{Y=0} = \psi_0 + \Phi_A + \frac{R}{\beta'} - 1 \qquad \text{(A-38)}$$

$$\left[\frac{d\psi}{dY}\right]_{Y=1} = 0 \qquad \text{(A-39)}$$

Particular Solution

Application of these boundary conditions to equation (A-36) gives the following particular solution:

$$\psi = g'K\left[(1+a')e^{\frac{Pe}{2}[(1-a')Y+a']} - (1-a')e^{\frac{Pe}{2}[(1+a')Y-a']}\right]$$

(A-40)

where

$$g' = \frac{2}{(1+a')^2 e^{\frac{Pe}{2}a'} - (1-a')^2 e^{-\frac{Pe}{2}a'}} \tag{A-41}$$

$$K = 1 - \phi_A - R/\beta_A \tag{A-42}$$

Determination of T_A

Now

$$\psi = \phi - \phi_A - R/\beta_A \tag{A-34}$$

ϕ_A (T_A/T_i) has to be determined. ϕ_A can be determined from the condition that all heat which enters the agitator must leave the agitator because no heat is stored or generated in the agitator. Mathematically this condition can be expressed as follows:

$$\int_0^L h_A \, dA_A (T_b - T_A) = 0 \tag{A-43}$$

In terms of ψ the above equation becomes

$$\int_0^1 (\psi + R/\beta_A) \, dY = 0 \tag{A-44}$$

ϕ_A can be determined from equation (A-44) after substituting for ψ from equation (A-40) and integrating between limits. ϕ_A is as follows:

$$\phi_A = \left(1 - \frac{R}{\beta'}\right) + \frac{R}{1-F'} \tag{A-45}$$

where

$$F' = 2a'g'e^{Pe/2} \tag{A-46}$$

Rearranging Particular Solution to Have $\frac{T_o - T_i}{T_L - T_i}$ as Dependent Variable

After substituting for ϕ_A from equation (A-45) equation (A-40) can be rearranged as follows:

$$\frac{T_o - T_i}{T_L - T_i} = \frac{g'\left[(1+a')e^{\frac{Pe}{2}a'} - (1-a')e^{-\frac{Pe}{2}a'}\right] - 1}{2a'g'e^{Pe/2} - 1} \qquad \text{(A-47)}$$

This equation is exactly the same as equation (A-14) for the constant wall temperature case with a' and g' replaced with a and g. Now a = a' and g = g' if $\beta = \beta'$. Now

$$\beta = \frac{hPL}{Wc} = \frac{hA}{Wc} \qquad \text{(A-7)}$$

$$\beta' = \frac{h_A P_A L}{Wc} = \frac{h A_A}{Wc} \qquad \text{(A-31)}$$

thus $\beta = \beta'$ if $hP = h_A P_A$. It is logical to assume $h = h_A$ but $P \neq P_A$. In fact

$$\frac{P_A}{P} \approx \frac{2D}{\pi D} = \frac{2}{\pi} = 0.64$$

thus $\beta' \approx 0.64\beta$.

Then for constant heat flux the effect of infinite agitator conduction will be less than if the wall temperature were constant. And further the agitator conductivity is finite; therefore, the effect of agitator conduction will be even less than equation (A-47) predicts.

It should be noted that the relationship between $\frac{T_o - T_i}{T_L - T_i}$ and β' and Pe is presented in Figure 24.

To summarize briefly, the effect of agitator conduction will not influence the calculated values of α_E if testing is conducted at sufficiently small values of β'.

APPENDIX B

THERMOCOUPLE CALIBRATIONS

The eleven wall thermocouples and the exchanger inlet line (pump outlet line) and exchanger outlet line thermocouples (thermocouples 1 thru 13 on Figure 3) were constructed from 30 gauge, teflon-covered iron-constantan wires. The thermocouple junctions were made with a mercury-bath thermocouple welder. These thermocouples were made of consecutive lengths from a roll of constantan thermocouple wire. The exchanger inlet and exchanger outlet thermocouples (thermocouples 14 thru 15 on Figure 3) were purchased from the Conax Company, Buffalo, New York. They were made of 30 gauge iron-constantan thermocouple wires in a 1/16 inch diameter stainless-steel sheath.

The above-mentioned fifteen thermocouples were calibrated in the Research and Development Laboratories of Phillips Petroleum Company. The calibration was performed in a constant-temperature silicone-oil bath. The bath container was an uninsulated, open-top, two-quart Dewar flask. The bath temperature was controlled by a thermistor temperature controller.

The calibration potentiometer was a Minneapolis-Honeywell model 2781 with a Minneapolis-Honeywell model 3117 spotlight galvanometer.

The calibration procedure was to start the readings immediately after cutoff of the control heater and take the readings as the bath cooled down. At all calibration temperatures a set of readings was taken going from thermocouple 1 to thermocouple 15 and then a set of readings was taken going from thermocouple 15 to thermocouple 1.

The thermocouples were calibrated against mercury-in-glass thermometers. The specifications of these thermometers are as follows: The thermometers for 100 F and 200 F were manufactured by the Precision Thermometer and Instrument Company, Southhampton, Pennsylvania. The smallest graduation was 0.05 F. The serial numbers were 714381 and 723216, respectively. The reference thermometer for 130 F and 160 F were ASTM Kinematic Viscosity, graduated in 0.1 F, and ASTM Paraffin Melting Point, graduated in 0.2 F, respectively. They were manufactured by the Taylor Company, Rochester, New York. The serial numbers were 2320641 and 4192122, respectively.

The calibrations are given in Table I.

TABLE I

THERMOCOUPLE CALIBRATIONS

Reference Thermometer	103	103	103	131.5	131.25	164.25	164.2	205.63	205.73	206.13
1	2.0339	2.0339	2.0281	2.8579	2.8525	3.8320	3.8255	5.0885	5.0950	5.1060
2	2.0332	2.0332	2.0271	2.8580	2.8512	3.8316	3.8270	5.0895	5.0960	5.1075
3	2.0340	2.0340	2.0284	2.8586	2.8539	3.8326	3.8314	5.0934	5.0995	5.1110
4	2.0340	2.0329	2.0281	2.8583	2.8531	3.8314	3.8309	5.0929	5.0979	5.1095
5	2.0326	2.0326	2.0278	2.8585	2.8524	3.8300	3.8292	5.0961	5.0975	5.1072
6	2.0327	2.0319	2.0285	2.8586	2.8534	3.8295	3.8311	5.0946	5.1000	5.1085
7	2.0327	2.0322	2.0284	2.8591	2.8541	3.8305	3.8329	5.0956	5.0999	5.1094
8	2.0327	2.0315	2.0290	2.8581	2.8541	3.8296	3.8318	5.0965	5.0996	5.1100
9	2.0327	2.0309	2.0284	2.8586	2.8546	3.8321	3.8331	5.0979	5.1004	5.1095
10	2.0325	2.0309	2.0289	2.8581	2.8553	3.8305	3.8331	5.0985	5.1011	5.1107
11	2.0325	2.0296	2.0284	2.8588	2.8561	3.8265	3.8332	5.0979	5.0999	5.1088
12	2.0320	2.0289	2.0266	2.8556	2.8525	3.8229	3.8265	5.0931	5.0941	5.1029
13	2.0320	2.0292	2.0274	2.8557	2.8530	3.8255	3.8281	5.0943	5.0942	5.1034
14	2.0272	2.0234	2.0224	2.8406	2.8388	3.8026	3.8084	5.0560	5.0562	5.0665
15	2.0250	2.0221	2.0232	2.8386	2.8376	3.8025	3.8105	5.0580	5.0580	5.0655
	*	*	**	*	**	*	**	*	**	*

* Readings taken from thermocouple 1 to 15
** Readings taken from thermocouple 15 to 1

APPENDIX C

TEST FLUID PHYSICAL PROPERTIES

Physical Properties of Ethylene Glycol

Heat Capacity and Thermal Conductivity

The heat capacity and thermal conductivity data at atmospheric pressure were taken from the Union Carbide Booklet number F-4763G, entitled "Glycols."

The heat capacity and thermal conductivity were curve-fitted by hand as linear functions of temperature. The resulting functions are as follows:

$$c = 0.517 + 0.0006T \qquad \text{(C-1)}$$

$$k = 0.186 - .000249T \qquad \text{(C-2)}$$

The maximum error between 80 F and 180 F was less than 0.3 percent for heat capacity and less than 0.4 percent for thermal conductivity.

Density

The density data were taken from both Union Carbide Booklet number F-4763G and from Eckert and Drake (16). The density was also hand curve-fitted as a linear function of temperature. The resulting functional is as follows:

$$\rho = 71.2545 - 0.02515\ T \qquad \text{(C-3)}$$

This curve fit is approximately 0.2 percent below the best straight line (a straight line fits the data as well as any other curve would fit the data) through the data from Eckert and Drake (16) and approximately 0.2 percent above the best straight line through the data from the booklet entitled "Glycols."

Viscosity

The viscosity data were also taken from Eckert and Drake (16) and from Union Carbide Booklet number F-4763G. The logarithm of viscosity was plotted vs. temperature and a smooth curve was drawn through the data. Data from both sources deviated a maximum of 3 percent from the smooth curve. This smooth curve was curve-fitted by regression analysis on a digital computer. The viscosity and temperature were entered into the computer at 5 F intervals from the smooth curve. The resulting curve fit is as follows (viscosity in centipoises):

$$\ln(\mu) = 5.17589 - 0.03822136T + 0.0001134165T^2 - 0.0000001463195T^3 \qquad \text{(C-4)}$$

The largest error in the curve fit between 80 F and 180 F was 0.61 percent at 110 F.

Physical Properties of Gulf Harmony Oil 151

The physical properties of Gulf Harmony Oil 151 were obtained from Mr. R. T. Kern, Jr., Staff Engineer, Gulf Research and Development Company, Marketing Technical Division, P. O. Drawer 2038, Pittsburgh, Pennsylvania.

The physical properties supplied by Mr. Kern are given in Table C-1.

The heat capacity, thermal conductivity and density data were hand curve-fitted as linear functions of temperature. The resulting functionals as as follows:

$$c(\text{Btu/lbF}) = 0.402 + 0.000586T \quad \text{(C-5)}$$

$$k(\text{Btu/hrftF}) = 0.0761 - 0.0000226T \quad \text{(C-6)}$$

$$\rho\ (\text{lb/ft}^3) = 58.03 - 0.03413T \quad \text{(C-7)}$$

The maximum errors in these curve fits are 0.65 percent for specific heat, 0.28 percent for thermal conductivity and 0.43 percent for density.

The viscosity data were plotted as viscosity in centistokes vs. temperature on an A.S.T.M. Standard Viscosity-Temperature Chart for Liquid Petroleum Products (D341). All data points were within 3 percent of a straight line.

The viscosity was determined at 100 F and 210 F in the Research and Development Laboratories of Phillips Petroleum Company, Bartlesville, Oklahoma (Phillips Research Notebook 14401-6). The viscosity was 517.1 centistokes at 100 F and 31.88 centistokes at 210 F. These data are within 3 percent of the straight line through the data supplied by Mr. Kern. This straight line relationship on the A.S.T.M. viscosity paper was curve-fitted by regression analysis on a digital computer. The viscosity and temperature were entered into the computer at 5 F intervals from the smooth curve. The resulting curve fit is as follows (viscosity in centistokes):

$$\text{Log}(\mu) = 11.79908 - 0.07765174T + 0.0002598315T^2 - 0.000000377051T^3 \quad \text{(C-8)}$$

The largest error in the curve fit was 1.48 percent at 105 F.

TABLE II

PHYSICAL PROPERTIES OF GULF HARMONY OIL 151

Temp. (F)	Viscosity (Saybolt Universal Seconds)	Density (gm/cc)	Thermal Conductivity (Btu/hr/sq ft/F/in)	Specific Heat (Btu/lb/F)
50	23,000	0.8993	0.90	0.433
100	2,520	0.8764	0.89	0.457
150	545	0.8518	0.87	0.490
200	183	0.8176	0.86	0.519

APPENDIX D

EXPERIMENTAL AND REDUCED DATA

Both heat transfer and power requirement data were reduced on the IBM 7094 digital computer.

The FORTRAN listing of the computer program to reduce the data from the heat transfer experiments is given in Table III.

The FORTRAN listing of the computer program to reduce the data from the agitator power requirement experiments is given in Table IV.

The computer program nomenclature is given in the NOMENCLATURE section immediately after the nomenclature for the main body of the thesis.

Experimental and reduced data from the heat transfer tests as output from the computer are presented for the tests with Gulf Harmony Oil 151 as the test liquid for the 3.500, 3.831, 4.000 and 4.039 inch diameter blades in Tables V, VI, VII and VIII, respectively. Such data for the tests with ethylene glycol for the 4.000 inch diameter blade are presented in Table IX.

Experimental and reduced data from the agitator power requirement tests as output from the computer are presented for the tests with Gulf Harmony Oil 151 as the test liquid for the 3.500, 3.831, 4.000 and 4.039 inch diameter blades in Tables X, XI, XII and XIII, respectively.

TABLE III

FORTRAN STATEMENTS FOR HEAT TRANSFER DATA REDUCTION PROGRAM

```
$IBFTC MAIN    NODECK
      DIMENSION TWMV(11), TW(11), WRIT(15,26), WROT(15,21)
      DIMENSION NRMA(4), DAIA(4)
C CURVE FIT IRON-CONSTANTAN THERMOCOUPLE TABLES IN  DEG. F VS. MV
      TEMP(A) = 32.36685 + (35.329 + (-.2902832 + (.011734 - .00015831
     1*A)*A)*A)*A
C PHYSICAL PROPERTIES - ENGLISH UNITS EXCEPT ETHYLENE GLYCOL VISCOSITY I
C CENTIPOISES AND OIL VISCOSITY IN CENTISTOKES
      XC(B)= .402 + .000586 *B
      XXK(C)= .0761 - .0000226 *C
      DEN(D) = 58.03 - .03413 * D
      VIS(E) = 2.71828183 ** (11.79908 + (-.07765174 + (.0002598315 -
     1 .000000377051 * E) * E) * E)
      W1 = 241.5 / 453.6
      W2 = 405.5 / 453.6
      W3 = 551.0 / 453.6
      DAI = 3.500
      DAIA(4) = 4.039
      DAIA(3) = 4.000
      DAIA(2) = 3.831
      DAIA(1) = 3.500
      P = 3.1416 * 4.058 / 12.0
      XL = 21.75 / 12.0
      I = 0
      LPC = 0
      D = 4.058 / 12.0
      M = 1
  141 CONTINUE
      L = 0
    1 READ (5,100) TM1,TMD,TM2,TWMV,TEOLMV,TEILMV,TEIMV,TEOMV,VOLTS,
     1AMPS,CIS,CIF,TI,TFLOW,POT,NW,XLA
  100 FORMAT (A5,A1,A4,14F5.3/F5.3,2F5.2,3F5.0,F5.2,F5.1,I5,F5.2)
      I = I + L
      L = L + 1
      DAI = DAIA(M)
      DA = DAI / 12.0
      DO 3 N = 1,11
      TWMVN = TWMV(N)
    3 TW(N) = TEMP(TWMVN)
      TEIL = TEMP(TEILMV)
      TEOL = TEMP(TEOLMV)
      TEI = TEMP(TEIMV) + 0.8
      TEO = TEMP(TEOMV) + 0.8
      TWAVG = 0.0
      DO 5 N=1,11
    5 TWAVG = TW(N) / 11. + TWAVG
      TWM = (TW(4) + TW(5)) / 2.0
      TEAVG = (14.0/22.0)*TEOL + (8.0/22.0)*TEI
      DELTF = TWM - TEAVG
      DELTF = TEOL - TEIL
      DO 119 K = 1,2
      TFILM = (TWM   + TEAVG) / 2.0
C PHYSICAL PROPERTIES
      XK =XXK(TFILM)
      C =XC(TFILM)
      DENB = DEN(TEAVG)
      DENW = DEN(TWM)
      DENWA = DEN(TWAVG)
      VISB = VIS(TEAVG) * DENB * 2.42 / 62.4
      VISWM = VIS(TWM) * DENW * 2.42 / 62.4
      VISWA = VIS(TWAVG) *DENWA * 2.42 / 62.4
      VISR = VISB / VISWM
C HEAT FLUX
      Q = VOLTS * AMPS * 3.41304
      QL = (0.464 + 0.0019*(TW(4) - 72.0)) * (TW(4) - 72.0)
      Q = Q - QL
      QOA = Q / 1.9256
      QOAR = 1.0 + (4.014/Q)*(TW(3) + TW(6) - TW(4) - TW(5))*36.0/2.0
C FLOW PARAMATERS (MEASURED VOL 384 CU IN .2225 CU FT 1.67 GAL)
      WLBH = .2225 * 3600. * DEN(TEOL) / TFLOW
      REA = 4.0 * WLBH / (3.1416 *D*VISB )
      VFPM = .2225 * 60. / (3.1416 *D *D / 4.  * TFLOW )
      AGRPM = 6.11 * (CIF -CIS) / TI
      VAT = (3.1416 *DA * AGRPM) / 60.
      RER = VAT * 3600. * DA * DENB / VISB
      RERC = RER / 3.1416
C POWER
      IF (XLA.LT..05) GO TO 18
      IF (K.EQ.2) GO TO 74
      XLA = XLA + 4.75
      IF (NW.EQ.1) GO TO 11
      IF (NW.EQ.2) GO TO 12
      IF (NW.EQ.3) GO TO 13
      IF (NW.EQ.12) GO TO 14
      IF (NW.EQ.13) GO TO 15
      IF (NW.EQ.23) GO TO 16
   11 T = W1 * (XLA + .113)
      GO TO 17
   12 T= W2 * (XLA + .186 )
      GO TO 17
   13 T = W3 * (XLA + .257)
      GO TO 17
   14 T = (W1 + W2) * (XLA + .299)
      GO TO 17
   15 T = (W1 + W3) * (XLA + .370)
      GO TO 17
   16 T = (W2 + W3) * (XLA + .443)
   17 GO TO (51,52,53,54), M
C BEARING FRICTION 3.500 PADDLE
   51 IF (I.GT.132) GO TO 55
      IF (AGRPM.GT.300.) GO TO 56
      TF = 0.2 + 0.00167 * AGRPM
      GO TO 73
   56 TF = 0.7
      GO TO 73
   55 IF (AGRPM.GT.150.) GO TO 57
      TF = 0.4 + 0.0053 * AGRPM
      GO TO 73
   57 TF = 1.19
      GO TO 73
```

```
C BEARING FRICTION 3.831 PADDLE
   52 IF(AGRPM.GT.400.) GO TO 58
      TF = 0.25 + 0.00232 * AGRPM
      GO TO 73
   58 TF = 1.18
      GO TO 73
C BEARING FRICTION 4.000 PADDLE
   53 IF (AGRPM.GT.250.) GO TO 154
      TF = 0.12 + 0.0038 * AGRPM
      GO TO 73
  154 TF = 1.07
      GO TO 73
C BEARING FRICTION 4.039 PADDLE
   54 IF (AGRPM.GT.240.) GO TO 59
      TF = 0.1 + 0.0041 * AGRPM
      GO TO 73
   59 TF = 1.08
   73 T = T - TF
      POWER = T * AGRPM * 6.28 / 12.0
      HP = POWER / 33000.
      BR = HP / ((Q / 60.) * .02357)
   74 PN = POWER * 32.2 * 3600. / (DENB * AGRPM ** 3 * DA ** 4*XL )
C HEAT BALANCE
      QAGIT = HP * 60. / .02357
      GO TO 19
   18 QAGIT = 0.0
      HP = 0.0
      BR = 0.0
      T = 0.0
      PN = 0.0
   19 CONTINUE
      DELTEC= (Q + QAGIT) / (WLBH* C)
      TEOC = TEIL + DELTEC
      TEAVGC = (14.0/22.0)*TEOC + (8.0/22.0)*TEI
      IF (RER.GT.1000.) GO TO 78
      TEOL= TEOC
      TEAVG = TEAVGC
  119 CONTINUE
C EXP H  NU AND J
   78 DELTEC = TWM - TEAVGC
      DELTD = TWM - TEAVG
      HX = QOA / DELTD
      HC = QOA * QOAR / DELTD
      XNU = HC * D / XK
      PR = VISB * C / XK
      XJ  = XNU / PR ** .333333
      XJVIS = (VISWM/VISB) ** 0.18 * XJ
      XJVISC = XJVIS * QOAR
C AXIAL DISPERSION PARAMATERS
      BETA = HX * P * XL / (WLBH * C)
      TRATIO = (TEI - TEIL) / (TEOL- TEIL)
      IF (TRATIO.GT.0.01) GO TO 20
      TRATIO = 0.0
      PE = 0.0
      PEDA = 0.0
      GO TO 28
   20 IF (TRATIO.GT.0.75) GO TO 21
      IF (TRATIO.GT.0.25) GO TO 22
      GO TO 25
   21 PE = 1.5 - (2.25 + 6.0 * (TRATIO - 1.0)) **0.5
      GO TO 23
   22 PE = .25 * 40. ** (1. - TRATIO)
   23 PE = (1.0 - EXP(-PE)) / TRATIO
      PE = (1.0 - EXP(-PE)) / TRATIO
      GO TO 27
   25 PE = 1.0 / TRATIO
   27 PEDA = 1.0 / (PE * VAT * 12.4 / (VFPM * XL ) )
C OUTPUT
   28 WRIT(L,1) = TM1
      WRIT(L,2) = TM2
      DO 175 N = 1,11
  175 WRIT (L,N+2) = TW(N)
      WRIT(L,14) = TEIL
      WRIT(L,15) = TEI
      WRIT(L,16) = TEO
      WRIT(L,17) = TEOL
      WRIT(L,18) = TRATIO
      WRIT(L,19) = QL
      WRIT(L,20) = Q
      WRIT(L,21) = HC
      WRIT(L,22) = AGRPM
      WRIT(L,23) = RER
      WRIT(L,24) = WLBH
      WRIT(L,25) = TORQUE
      WRIT(L,26) = HP
C THE NUMBER OF RUNS  FOR EACH AGITATOR DIAMETER ARE  144 FOR 3.500  84
C FOR 3.831  90 FOR 4.000 AND  46 FOR 4.039
      IF (I.EQ.144) GO TO 301
      IF (I.EQ.228) GO TO 301
      IF (I.EQ.318) GO TO 301
      IF (I.EQ.364) GO TO 197
      GO TO 281
  301 M = M + 1
      GO TO 197
  281 IF (L.LT.15) GO TO 1
  197 WRITE (6,198)
  198 FORMAT (1H1    ////)
      WRITE (6,201) WRIT
  201 FORMAT (// 5X 6HDATE   15(3X A5)/ 5X 6HTIME   15(4X A4)  //
     1    5X 6HT(1)    15F8.2 //5X 6HT(2)    15F8.2 //5X 6HT(3)     15F8.2 //
     2    5X 6HT(4)    15F8.2 //5X 6HT(5)    15F8.2 //5X 6HT(6)     15F8.2 //
     3    5X 6HT(7)    15F8.2 //5X 6HT(8)    15F8.2 //5X 6HT(9)     15F8.2 //
     4    5X 6HT(10)   15F8.2 //5X 6HT(11)   15F8.2 //5X 6HTEIL     15F8.2 //
     5    5X 6HTEI     15F8.2 //5X 6HTEO     15F8.2 //5X 6HTEOL     15F8.2 //
     6    5X 6HTRATIO  15F8.2 //5X 6HQL      15F8.2 //5X 6HQ        15F8.2 //
     7    5X 6HHC      15F8.2 //5X 6HAGRPM   15F8.2 //5X 6HRER      15F8.1 //
     8    5X 6HWLBH    15F8.1 //5X 6HTORQUE  15F8.1 //5X 6HHP       15F8.2 //
     9         )
  999 GO TO 141
      END
```

TABLE IV

FORTRAN STATEMENTS FOR AGITATOR POWER REQUIREMENT DATA REDUCTION PROGRAM

```
      DIMENSION DAIA (4)
C CURVE FIT IRON-CONSTANTAN THERMOCOUPLE TABLES IN  DEG. F VS. MV
      TEMP(A) = 32.36685 + (35.329 + (-.2902832 + (.011734 - .00015831
     1*A)*A)*A)*A
      DEN(D) = 58.03 - .03413 * D
      VIS(E) = 2.71828183 ** (11.79908 + (-.07765174 + (.0002598315 -
     1 .000000377051 * E) * E) * E)
      LPC =52
      W1 = 241.5 / 453.6
      W2 = 405.5 / 453.6
      W3 = 551.0 / 453.6
      XL = 21.75 / 12.0
      DAIA(1) = 3.500
      DAIA(2) = 3.831
      DAIA(3) = 4.000
      DAIA(4) = 4.039
      DAI = 3.5000
      DA = DAI / 12.0
      I = 0
      M = 1
    1 READ(5,100)TM1,TM2,NW,XLA,TWMV,TEIMV,TEOMV,CIS,CIF,TIMEM,TIMES
  100 FORMAT (A6, A4, I5, 8F5.0)
      I = I + 1
      TWM = TEMP(TWMV)
      TEI = TEMP(TEIMV)
      TEO = TEMP(TEOMV)
      TEAVG =(TEI +       TEO) / 2.0
      DENB = DEN(TEAVG)
      DENW = DEN(TWM)
      VISB = VIS(TEAVG) * DENB * 2.42 / 62.4
      VISW  = VIS(TWM) * DENW * 2.42 / 62.4
      TI = TIMEM + TIMES / 60.0
      AGRPM = 6.11 * (CIF -CIS) / TI
      RER = AGRPM * 60.0 * DENB * DA **2 / VISB
      XLA = XLA + 4.75
      IF (NW.EQ.1) GO TO 11
      IF (NW.EQ.2) GO TO 12
      IF (NW.EQ.3) GO TO 13
      IF (NW.EQ.12) GO TO 14
      IF (NW.EQ.13) GO TO 15
      IF (NW.EQ.23) GO TO 16
      IF (NW.EQ.123) GO TO 116
   11 T = W1 * (XLA + .113                  )
      GO TO 17
   12 T= W2 * (XLA + .186 )
      GO TO 17
   13 T = W3 * (XLA + .257)
      GO TO 17
   14 T = (W1 + W2) * (XLA + .299)
      GO TO 17
   15 T = (W1 + W3) * (XLA + .370)
      GO TO 17
   16 T = (W2 + W3) * (XLA + .443)
      GO TO 17
  116 T = (W1 + W2 + W3) * (XLA + 0.556)
   17 GO TO (51,52,53,54), M
C BEARING FRICTION 3.500 PADDLE
   51 IF (I.GT.65) GO TO 55
      IF (AGRPM.GT.300.) GO TO 56
      TF = 0.2 + 0.00167 * AGRPM
      GO TO 73
   56 TF = 0.7
      GO TO 73
   55 IF (AGRPM.GT.150.) GO TO 57
      TF = 0.4 + 0.0053 * AGRPM
      GO TO 73
   57 TF = 1.19
      GO TO 73
C BEARING FRICTION 3.831 PADDLE
   52 IF(AGRPM.GT.400.) GO TO 58
      TF = 0.25 + 0.00232 * AGRPM
      GO TO 73
   58 TF = 1.18
      GO TO 73
C BEARING FRICTION 4.000 PADDLE
   53 IF (AGRPM.GT.250.) GO TO 154
      TF = 0.12 + 0.0038 * AGRPM
      GO TO 73
  154 TF = 1.07
      GO TO 73
C BEARING FRICTION 4.039 PADDLE
   54 IF (AGRPM.GT.240.) GO TO 59
      TF = 0.1 + 0.0041 * AGRPM
      GO TO 73
   59 TF = 1.08
   73 T = T - TF
      POWER = T * AGRPM * 6.28 / 12.0
      HP = POWER / 33000.
      PN = POWER * 32.2 * 3600. / (DENB * AGRPM ** 3 * DA ** 4*XL )
      QAGIT = HP * 60. / .02357
      IF (I.EQ.0) GO TO 197
      IF (I.EQ. 76) GO TO 301
      IF (I.EQ.111) GO TO 301
      IF (I.EQ.219) GO TO 301
      IF (LPC.LT.26)  GO TO 29
      GO TO 197
  301 M = M + 1
      DAI = DAIA(M)
      DA = DAI / 12.0
  197 WRITE (6,198)
  198 FORMAT (1H1 /////)
      WRITE (6,110)
  110 FORMAT (     4X 9HDATE        5HNW     8HXLA       8HTW
     18HTF        7H T        9HTEAVG      9HVISW      10HVISB
     27HHP      8HQAGIT      11HAGRPM       9HRER        2HPN / )
      LPC = 0
   29 WRITE(6,120)TM1,TM2,NW,XLA,TWM,TF , T ,TEAVG,VISW,VISB,HP,QAGIT,
     1        AGRPM,RER,PN
  120 FORMAT (1H A6,A4,I4,F7.2,4F8.2,2F9.2,F9.5,F6.2,3F9.2 /)
      LPC = LPC + 1
      GO TO 1
      END
```

TABLE V

DATA FOR HEAT TRANSFER TESTS WITH GULF HARMONY OIL 151 AND THE 3.500 INCH DIAMETER BLADE

DATE TIME	03/29 1620	03/29 1645	03/29 1710	03/29 1810	03/29 1830	03/29 1843	03/29 1900	03/29 1915	03/29 1930	03/29 1945	03/29 2005	03/29 2025	03/29 2040	03/29 2050	03/29 2060
T(1)	124.13	121.47	122.97	119.77	120.62	118.71	116.46	114.48	113.29	115.68	112.98	111.27	109.83	108.94	108.33
T(2)	126.07	123.11	123.96	120.89	122.02	120.59	118.71	117.21	116.36	118.40	116.12	114.45	112.81	111.85	111.00
T(3)	127.02	123.85	123.96	121.30	122.36	121.61	118.71	119.32	118.78	120.59	118.92	117.31	115.78	114.55	113.63
T(4)	126.54	123.28	122.94	120.69	121.81	121.27	118.71	119.80	119.60	121.23	120.25	118.88	117.48	116.22	115.30
T(5)	125.15	121.74	121.61	119.53	120.42	119.77	119.26	119.19	119.36	120.55	120.28	119.29	118.00	117.01	116.12
T(6)	123.17	119.94	119.87	117.89	118.54	118.00	117.48	117.89	118.06	119.19	119.63	118.75	117.59	116.63	115.98
T(7)	120.65	117.38	117.72	116.02	116.19	115.61	114.96	115.20	115.71	116.80	117.72	117.21	116.36	115.47	114.92
T(8)	117.59	114.48	115.33	113.83	113.49	112.64	111.95	112.19	112.94	113.76	115.03	114.82	114.00	113.32	112.98
T(9)	114.24	111.30	112.77	111.37	110.65	109.35	108.46	108.50	109.15	110.18	111.54	111.54	111.06	110.52	110.31
T(10)	110.48	107.78	110.21	108.84	107.61	105.55	104.49	104.18	104.90	106.07	107.30	107.61	107.34	107.10	107.13
T(11)	107.57	105.04	108.29	108.53	105.18	102.95	101.27	100.79	101.20	102.47	103.36	103.84	103.81	103.67	104.05
TEIL	84.78	82.02	79.94	80.11	80.91	81.60	82.12	82.50	83.43	84.40	85.57	86.06	86.33	86.68	87.13
TEI	86.96	84.06	81.33	81.02	81.99	83.16	83.71	84.16	85.24	86.20	87.44	88.20	88.62	89.31	90.10
TEO	87.62	84.37	81.71	81.26	82.40	83.68	84.96	85.68	88.69	87.93	89.58	90.41	91.24	92.00	92.96
TEOL	87.80	85.00	82.96	83.20	84.00	84.65	85.22	85.64	86.63	87.55	88.89	89.64	90.21	90.90	91.73
TRATIO	0.72	0.68	0.46	0.29	0.35	0.51	0.51	0.53	0.56	0.57	0.56	0.60	0.59	0.62	0.65
QL	30.96	28.79	28.56	27.10	27.83	27.47	25.82	26.52	26.39	27.45	26.81	25.93	25.04	24.23	23.65
Q	510.25	512.42	519.98	519.71	521.80	512.66	504.91	504.21	502.63	503.28	503.92	503.09	505.69	506.49	507.07
HC	5.44	5.81	6.09	6.14	5.84	5.84	5.70	5.68	5.45	5.50	5.88	6.07	6.52	7.08	7.95
AGRPM	101.76	100.89	59.09	58.60	77.79	116.50	156.73	197.37	238.28	198.39	298.47	381.28	463.67	548.15	630.84
RER	49.7	43.8	23.3	23.1	31.9	49.4	68.1	87.3	110.0	95.1	151.0	198.9	246.9	300.0	356.7
WLBH	364.3	371.1	373.4	365.4	365.2	363.5	363.4	364.2	364.0	361.4	361.1	355.1	353.5	353.4	353.2
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.03	0.05	0.07	0.10

TABLE V (Continued)

DATE TIME	03/29 2110	03/29 2120	03/29 2130	03/29 2135	03/31 1110	03/31 1120	03/31 1140	03/31 1152	03/31 1202	03/31 1220	03/31 1232	03/31 1245	03/31 1257	03/31 1307	03/31 1314
T(1)	108.16	104.87	101.78	103.16	120.79	120.82	124.47	122.80	119.63	118.10	115.71	113.63	112.06	110.76	109.70
T(2)	110.52	105.76	100.93	102.33	124.88	123.28	125.93	123.00	122.12	120.93	118.88	116.97	115.47	114.24	113.05
T(3)	112.88	106.27	99.76	101.54	124.88	124.88	126.71	125.93	124.19	123.17	119.90	120.04	118.68	117.35	116.29
T(4)	114.58	106.48	99.00	100.55	125.01	125.05	126.13	125.69	124.50	123.99	122.80	121.54	120.25	119.15	118.06
T(5)	115.47	107.13	98.21	99.72	123.89	124.02	124.74	122.70	123.68	123.34	122.60	121.78	120.72	119.87	118.88
T(6)	115.47	108.12	97.66	99.38	122.29	122.29	122.87	122.53	121.98	121.95	121.61	120.96	120.28	119.56	118.61
T(7)	114.45	108.53	97.32	98.49	119.77	119.73	120.59	120.04	119.53	119.56	119.43	120.93	122.15	118.13	117.38
T(8)	112.70	108.09	97.32	97.87	116.63	116.67	117.86	118.85	116.36	116.39	116.60	116.53	116.29	115.85	115.27
T(9)	110.14	108.64	97.84	97.90	113.11	112.98	114.75	113.76	112.74	112.64	112.88	112.91	112.88	112.64	112.19
T(10)	107.40	105.11	98.56	98.14	126.17	109.15	111.51	110.18	108.46	108.33	108.29	108.46	108.46	108.50	108.16
T(11)	104.66	103.40	98.52	98.25	105.86	106.03	109.01	107.30	105.18	104.77	104.36	104.32	104.36	104.42	104.22
TEIL	87.99	89.27	90.99	92.16	82.29	81.84	81.77	81.77	81.95	82.05	84.09	82.53	83.05	83.33	83.40
TEI	91.41	92.13	93.65	97.26	84.13	83.54	82.78	83.16	83.65	84.06	84.72	84.99	85.58	85.93	86.24
TEO	94.34	96.44	99.15	101.79	85.75	85.20	83.96	84.37	86.20	86.65	85.86	88.00	89.00	89.79	90.17
TEOL	93.34	95.24	98.16	101.02	87.33	86.88	86.82	86.80	86.99	87.15	89.47	88.05	88.66	89.11	89.43
TRATIO	0.64	0.48	0.37	0.58	0.36	0.34	0.20	0.28	0.34	0.39	0.12	0.45	0.45	0.45	0.47
QL	23.20	18.26	13.91	14.79	29.94	29.96	30.69	30.39	29.60	29.26	28.47	27.65	26.81	26.10	25.40
Q	509.23	515.24	517.87	516.99	467.91	467.89	469.22	466.84	470.31	475.41	477.86	477.02	473.10	467.01	472.44
HC	8.95	23.41	132.43	607.30	4.65	4.41	4.87	6.33	4.41	4.35	2.93	4.63	5.17	5.17	5.58
AGRPM	756.48	874.89	986.55	1093.58	98.62	98.67	60.27	79.79	118.38	137.01	176.33	215.28	255.83	296.17	337.17
RER	453.8	555.9	687.5	857.3	45.6	44.7	26.9	35.8	53.8	63.0	87.0	102.7	125.1	147.3	169.9
WLBH	352.9	359.7	359.0	358.4	200.4	200.5	200.5	200.5	201.4	201.4	198.4	197.6	197.6	194.0	194.0
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.14	0.19	0.26	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03

TABLE V (Continued)

DATE TIME	03/31 1329	03/31 1340	03/31 1350	03/31 1359	03/31 1406	03/31 1415	03/31 1643	03/31 1702	03/31 1715	03/31 1730	03/31 1745	03/31 1800	03/31 1814	03/31 1830	03/31 1840
T(1)	109.01	108.36	107.99	107.75	107.64	107.61	148.83	162.06	156.68	164.38	167.47	171.16	169.11	149.16	143.12
T(2)	112.23	111.61	111.13	110.72	110.45	110.31	150.38	166.46	159.71	168.91	172.33	176.18	174.24	150.58	143.63
T(3)	115.47	114.79	114.21	115.37	113.25	113.08	151.56	170.92	162.53	173.77	177.25	181.03	179.06	151.46	143.73
T(4)	117.28	116.49	116.02	115.47	115.13	114.58	152.03	173.50	164.01	176.25	179.59	183.34	181.40	152.64	143.83
T(5)	118.10	117.52	116.90	118.17	116.15	115.95	153.31	174.94	165.35	177.62	180.76	184.10	182.33	154.15	144.20
T(6)	117.93	117.31	116.84	118.17	116.19	115.81	155.00	174.51	165.05	177.08	180.16	182.97	181.43	155.70	145.35
T(7)	116.70	116.26	115.85	115.47	115.27	115.10	155.84	172.60	165.76	174.84	177.65	179.99	178.82	122.49	146.09
T(8)	114.75	114.28	113.93	115.30	113.39	113.29	155.57	168.98	162.50	171.22	173.44	175.34	174.37	155.87	146.43
T(9)	111.75	111.41	111.10	110.93	110.86	110.72	153.99	164.21	160.11	165.96	167.87	169.25	168.61	154.29	146.40
T(10)	107.92	107.61	107.51	107.44	107.47	107.57	151.09	158.63	156.38	159.91	161.19	162.03	161.52	151.29	145.35
T(11)	104.05	103.84	104.01	104.08	104.18	104.42	147.54	153.31	152.07	154.12	154.66	154.86	154.79	152.94	142.98
TEIL	83.57	83.88	84.23	84.75	84.95	85.26	116.80	115.50	116.05	115.47	115.16	114.62	114.82	116.56	116.97
TEI	86.72	88.79	87.93	88.38	89.03	89.48	118.86	118.28	118.73	118.39	117.98	116.99	117.47	118.76	118.49
TEO	90.55	91.10	91.82	92.44	92.99	93.51	123.94	122.24	123.16	120.09	121.62	120.36	120.87	123.77	124.11
TEOL	89.84	90.32	91.00	91.80	92.19	92.74	123.94	122.26	122.99	122.09	121.73	121.08	121.33	123.44	124.04
TRATIO	0.50	0.76	0.55	0.51	0.56	0.56	0.29	0.41	0.39	0.44	0.43	0.37	0.41	0.32	0.21
QL	24.90	24.41	24.10	23.76	23.55	23.20	49.30	66.67	58.78	69.02	71.92	75.21	73.50	49.77	43.13
Q	475.00	471.79	473.74	474.09	474.30	474.64	1318.95	1306.03	1307.78	1282.54	1279.65	1267.53	1275.33	1294.00	1298.96
HC	5.95	6.36	6.61	9.23	7.20	7.80	23.89	10.58	14.16	9.84	9.26	8.25	8.73	21.66	32.46
AGRPM	378.14	414.99	462.21	503.69	547.85	589.75	348.06	305.02	318.38	266.11	225.55	185.00	203.79	347.21	387.56
RER	193.9	222.1	248.6	278.3	308.5	339.0	585.0	492.6	524.3	428.8	359.1	287.4	320.0	577.1	650.0
WLBH	194.8	194.7	193.8	193.7	197.1	198.0	391.8	395.8	395.6	395.8	397.7	399.7	399.7	399.1	395.3
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.04	0.04	0.05	0.06	0.07	0.08	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.02

TABLE V (Continued)

DATE TIME	03/31 1851	03/31 1904	03/31 1914	03/31 1925	03/31 1936	03/31 1950	03/31 2000	03/31 2010	03/31 2020	03/31 2030	03/31 2040	03/31 2050	04/03 1500	04/03 1515	04/03 1545
T(1)	135.27	135.84	133.64	132.86	134.01	133.84	133.03	133.16	132.89	133.03	133.54	133.98	168.54	168.14	172.73
T(2)	133.54	134.05	132.15	131.50	133.50	133.67	132.82	132.86	132.96	133.20	133.67	134.21	168.04	165.45	169.45
T(3)	131.77	132.25	130.52	129.91	132.21	132.62	132.32	132.25	132.35	132.72	133.23	133.71	166.13	162.94	166.80
T(4)	130.79	131.30	129.74	129.12	131.30	131.81	131.37	131.47	131.77	132.15	132.65	133.20	165.62	162.60	166.39
T(5)	130.08	130.65	129.33	128.48	130.48	130.92	130.41	130.79	130.99	131.47	131.94	132.52	163.91	161.69	154.75
T(6)	129.74	130.41	129.84	128.21	129.91	130.14	129.80	130.01	130.28	130.79	131.26	132.01	162.87	163.37	164.88
T(7)	129.60	130.55	132.01	128.75	129.23	129.43	129.16	129.50	129.74	130.11	130.75	131.33	162.43	165.22	165.59
T(8)	130.14	131.57	134.21	129.91	129.50	129.06	128.75	129.09	129.57	129.57	130.01	130.96	162.94	169.72	168.78
T(9)	132.18	134.05	136.38	132.38	130.72	129.60	129.12	129.26	129.06	129.26	129.60	130.38	165.35	173.64	175.04
T(10)	134.42	136.38	137.57	134.08	130.55	130.31	129.60	128.95	128.92	128.99	129.26	130.01	167.33	176.68	178.99
T(11)	134.52	135.91	136.86	133.71	131.47	129.74	128.75	128.61	127.97	128.11	128.41	129.09	165.25	174.57	177.45
TEIL	117.65	117.38	117.35	117.42	117.93	117.72	117.14	117.55	117.72	118.10	118.61	119.36	137.13	136.76	138.11
TEI	118.66	118.59	118.73	119.17	119.72	119.51	119.00	119.44	120.02	120.70	121.25	122.24	138.20	137.32	138.61
TEO	124.65	124.45	124.48	124.99	125.30	125.34	124.96	125.27	125.81	126.46	127.14	127.89	146.52	146.12	147.06
TEOL	124.95	124.64	124.75	124.99	125.58	125.01	124.54	124.74	125.18	125.69	126.20	127.12	146.02	145.76	147.38
TRATIO	0.14	0.17	0.19	0.23	0.23	0.25	0.25	0.26	0.31	0.34	0.35	0.37	0.12	0.06	0.05
QL	33.84	34.19	33.12	32.71	34.19	34.55	34.24	34.31	34.52	34.78	35.13	35.51	60.09	57.63	60.73
Q	1314.34	1304.52	1302.88	1312.76	1311.27	1306.51	1309.53	1319.98	1298.77	1316.78	1319.81	1317.74	2668.29	2704.68	2714.24
HC	90.97	82.54	103.99	118.18	93.19	81.37	82.79	82.45	82.88	85.77	86.30	91.07	63.25	76.08	66.86
AGRPM	429.64	409.39	470.79	514.37	556.39	597.22	638.66	682.30	763.10	808.91	850.22	893.27	309.56	267.22	226.83
RER	735.0	695.6	802.8	885.6	975.1	1032.7	1087.8	1172.7	1331.6	1436.6	1534.2	1658.8	952.2	811.4	716.5
WLBH	395.1	391.6	391.6	391.5	391.4	391.5	391.6	391.6	393.2	393.1	394.8	394.6	609.6	611.5	594.6
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.02	0.02	0.03	0.04	0.05	0.05	0.06	0.07	0.10	0.11	0.13	0.14	0.00	0.00	0.00

TABLE V (Continued)

DATE TIME	04/03 1600	04/03 1610	04/03 1622	04/03 1640	04/03 1653	04/03 1705	04/03 1715	04/03 1730	04/03 1739	04/03 1750	04/03 1803	04/03 1813	04/03 1822	04/03 1830	04/03 1840
T(1)	171.49	169.92	168.98	168.41	167.10	166.43	165.52	165.42	164.25	163.91	162.90	161.76	161.02	161.22	161.83
T(2)	168.74	169.58	168.61	168.14	167.20	166.73	165.82	165.76	164.61	164.41	163.64	162.50	161.42	161.76	162.30
T(3)	167.70	167.47	166.86	167.30	166.02	165.76	165.35	165.08	164.18	164.18	163.20	162.23	161.29	161.49	162.10
T(4)	166.73	166.02	166.02	166.53	165.45	164.98	164.51	164.38	163.71	163.61	162.60	161.76	160.82	161.09	161.52
T(5)	165.79	163.54	164.72	164.78	164.08	163.64	163.10	163.24	162.36	162.33	161.52	160.65	159.78	159.98	160.35
T(6)	167.40	163.37	164.11	163.78	163.24	162.77	162.30	162.20	161.56	161.66	162.53	159.84	159.04	159.24	159.54
T(7)	169.38	162.73	163.27	163.00	162.53	162.26	161.52	161.52	160.72	160.68	159.67	158.87	158.06	158.33	158.70
T(8)	173.60	164.72	162.70	162.90	162.23	161.62	160.89	160.65	159.88	159.91	158.83	157.96	157.19	157.49	157.86
T(9)	178.25	168.47	164.35	163.34	162.67	161.52	160.41	159.98	159.17	159.04	157.99	157.29	156.71	156.71	157.15
T(10)	180.63	170.55	165.08	164.82	162.73	160.68	160.15	159.81	158.70	158.40	157.45	156.51	156.11	156.14	156.61
T(11)	178.42	169.41	163.61	162.50	160.58	158.87	157.96	157.52	156.48	156.14	155.13	154.36	154.19	154.19	154.42
TEIL	137.94	138.38	138.42	138.55	138.55	138.89	138.79	139.13	139.53	140.18	139.77	139.36	138.96	138.76	138.31
TEI	138.57	139.35	139.96	140.10	140.44	140.64	140.81	141.28	141.89	142.97	142.84	142.77	143.01	142.60	141.48
TEO	147.84	147.84	147.74	147.70	147.97	148.24	148.58	148.89	149.49	150.30	149.96	149.83	149.73	149.43	148.65
TEOL	147.20	147.44	146.97	146.90	147.24	147.68	147.78	148.22	148.59	149.40	149.23	149.03	149.03	148.73	148.05
TRATIO	0.07	0.11	0.18	0.18	0.22	0.20	0.22	0.24	0.26	0.30	0.32	0.35	0.40	0.39	0.33
QL	61.00	60.42	60.42	60.84	59.96	59.57	59.19	59.08	58.53	58.45	57.63	56.96	56.20	56.42	56.77
Q	2713.97	2703.39	2710.62	2728.33	2738.91	2749.61	2769.15	2783.57	2789.02	2804.41	2800.31	2790.60	2791.35	2795.10	2793.24
HC	67.87	71.58	67.62	66.33	70.61	74.20	77.53	79.12	85.05	91.33	99.95	99.41	106.97	102.53	94.40
AGRPM	245.94	286.70	329.08	348.42	389.39	433.37	476.88	519.06	596.84	684.10	772.72	856.09	948.55	907.77	771.64
RER	774.4	913.2	1046.0	1107.7	1248.9	1402.8	1548.7	1705.6	1984.6	2328.7	2619.8	2891.0	3210.4	3045.5	2533.4
WLBH	594.6	605.6	605.8	606.7	606.5	601.2	601.2	601.0	600.8	604.8	604.9	599.8	599.8	602.5	602.8
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.05	0.07	0.10	0.13	0.11	0.07

TABLE V (Continued)

DATE TIME	04/21 1053	04/21 1105	04/21 1120	04/21 1136	04/21 1156	04/21 1215	04/21 1238	04/21 1255	04/21 1310	04/21 1332	04/21 1355	04/21 1410	04/21 1420	04/21 1432	04/21 1450
T(1)	149.94	148.59	145.99	149.94	153.31	157.69	163.57	171.09	175.58	153.14	145.38	145.35	143.49	141.12	136.38
T(2)	153.55	153.95	151.09	155.54	159.17	163.61	169.45	176.48	180.63	158.93	150.38	150.38	148.25	145.35	140.01
T(3)	160.72	159.41	156.38	161.19	165.05	169.75	175.28	181.66	184.84	164.75	155.87	155.70	153.48	150.21	144.34
T(4)	162.06	160.82	157.82	162.57	166.23	170.96	176.31	181.93	184.60	165.92	157.29	157.05	153.25	151.66	146.03
T(5)	165.22	163.91	160.95	165.69	169.31	173.80	178.66	182.77	184.17	169.55	160.41	160.21	158.03	154.79	149.20
T(6)	163.74	162.57	159.74	164.35	167.57	171.83	175.98	178.62	179.29	167.67	159.37	159.17	157.49	154.15	149.27
T(7)	163.00	161.86	159.00	163.34	166.56	170.35	173.94	175.68	175.78	166.43	158.70	158.40	156.34	153.31	148.63
T(8)	159.37	158.26	155.54	159.57	162.50	165.69	168.61	169.58	169.21	162.33	155.23	154.93	153.01	150.21	145.99
T(9)	154.12	152.94	150.41	154.09	156.65	159.37	161.73	161.86	161.52	156.55	150.28	149.87	148.19	145.65	141.97
T(10)	147.04	146.03	143.69	146.73	148.83	151.12	152.94	152.98	152.64	148.86	143.66	143.29	141.87	139.84	137.03
T(11)	139.64	138.55	136.72	138.92	140.68	142.54	144.30	144.81	145.35	140.82	136.89	136.52	135.37	134.11	131.94
TEIL	95.12	94.43	94.09	93.64	93.19	92.68	91.99	91.68	91.16	93.71	94.67	94.40	94.23	94.60	95.02
TEI	101.11	100.32	100.49	98.91	98.26	97.50	96.54	94.89	95.16	98.67	101.21	100.83	101.00	101.76	102.38
TEO	108.89	107.96	107.93	106.53	105.70	104.64	103.27	101.42	99.73	106.22	108.58	108.14	108.41	109.09	109.71
TEOL	107.72	107.26	107.21	106.27	105.87	105.15	104.32	103.84	103.19	105.80	107.33	107.02	107.13	107.87	108.53
TRATIO	0.48	0.46	0.49	0.42	0.40	0.39	0.37	0.26	0.33	0.41	0.52	0.51	0.53	0.54	0.54
QL	57.20	56.20	53.82	57.61	60.59	64.52	69.08	73.97	76.34	60.34	53.39	53.21	50.24	49.02	44.76
Q	1312.75	1335.04	1328.46	1315.75	1329.59	1312.23	1307.68	1299.38	1294.26	1294.60	1309.37	1305.11	1318.66	1326.03	1321.38
HC	9.87	10.24	10.80	9.60	8.98	8.03	7.10	6.23	5.92	8.64	10.94	10.92	13.27	12.82	15.13
AGRPM	302.18	301.88	341.72	261.56	220.90	180.34	139.92	101.08	81.79	220.58	344.27	344.23	385.00	467.48	553.46
RER	290.9	284.7	322.6	236.8	196.4	156.2	117.3	82.0	65.6	196.9	329.0	325.0	365.3	455.3	551.5
WLBH	216.6	216.7	216.7	216.8	217.9	218.0	219.2	220.4	221.6	222.4	222.2	222.2	222.2	222.1	224.3
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.03	0.05

TABLE V (Continued)

DATE	04/21	04/21	04/21	04/21	04/21	04/21	04/21	05/24	05/24	05/24	05/24	05/24	05/24	05/24	05/24
TIME	1510	1528	1540	1550	1600	1610	1620	1147	1355	1430	1460	1525	1550	1625	1650
T(1)	126.17	123.04	121.27	122.19	123.21	124.16	124.74	123.82	147.68	143.32	138.86	134.83	131.98	129.91	128.72
T(2)	126.71	123.17	120.25	121.71	123.04	124.16	124.57	127.43	149.30	145.55	141.77	138.15	135.57	133.60	132.62
T(3)	127.22	122.80	118.23	120.55	122.12	123.17	123.96	131.13	150.21	147.34	144.30	141.33	139.13	137.23	136.38
T(4)	128.24	122.42	116.73	119.43	121.27	122.42	123.21	133.03	149.84	147.24	144.84	142.61	140.95	139.06	138.45
T(5)	129.84	121.95	114.41	117.72	119.56	120.89	121.91	134.52	148.59	146.26	144.44	142.61	141.29	139.94	139.43
T(6)	132.04	122.05	113.39	115.54	118.00	119.63	120.59	134.52	147.04	144.37	142.75	141.33	140.48	139.43	139.09
T(7)	132.96	122.83	113.83	113.76	116.36	118.13	119.09	133.40	144.64	141.50	139.94	138.82	138.31	137.57	137.57
T(8)	132.86	124.40	115.78	112.64	114.79	116.53	117.76	131.13	141.67	138.11	136.45	135.44	135.23	134.83	134.86
T(9)	131.70	124.84	117.69	113.46	114.00	115.85	116.87	127.80	138.42	134.15	132.15	131.16	131.13	130.89	131.13
T(10)	129.29	123.99	119.26	114.92	114.00	115.44	116.73	123.45	134.86	129.84	127.39	126.27	126.20	126.00	126.27
T(11)	125.93	121.85	118.57	114.75	113.59	114.58	115.47	118.85	131.81	126.44	123.41	121.95	121.61	121.44	119.90
TEIL	95.81	96.63	97.56	98.18	99.07	99.90	100.45	87.99	86.09	86.51	86.71	87.13	87.71	88.34	88.58
TEI	101.52	102.14	103.13	103.92	105.70	107.18	108.31	95.23	87.31	88.82	89.76	91.13	92.24	93.41	94.47
TEO	111.25	112.34	114.12	115.76	117.12	118.32	119.24	104.16	90.93	93.51	96.75	100.04	101.59	102.58	103.48
TEOL	110.20	111.98	113.79	114.24	115.71	117.07	117.96	103.03	99.35	99.61	100.02	100.66	101.57	102.65	102.97
TRATIO	0.40	0.36	0.34	0.36	0.40	0.42	0.45	0.48	0.09	0.18	0.23	0.30	0.33	0.35	0.41
QL	32.11	28.23	24.56	26.28	27.47	28.23	28.74	35.39	47.63	45.67	43.88	42.24	41.03	39.66	39.22
Q	1338.49	1354.05	1357.72	1357.71	1354.81	1351.29	1367.63	510.98	478.85	477.43	479.22	481.91	482.07	489.36	497.05
HC	33.63	52.31	127.76	82.28	81.10	83.41	84.89	5.78	3.77	3.54	3.42	3.39	3.52	4.14	4.30
AGRPM	639.79	716.30	806.29	890.00	962.71	1005.62	1034.13	209.61	21.48	40.71	59.52	79.80	98.70	118.71	138.71
RER	654.6	768.3	911.0	1025.6	1170.3	1281.3	1360.8	167.7	14.1	27.5	41.1	57.1	73.2	91.8	109.7
WLBH	224.1	222.7	222.4	221.2	221.0	220.8	220.7	75.4	76.2	77.0	76.2	75.4	73.7	72.4	73.1
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.07	0.10	0.13	0.17	0.21	0.22	0.24	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE V (Continued)

DATE	05/24	05/24	05/24	05/24	05/24	05/24	05/24	05/24	05/24	05/24	05/24	05/24	05/24	05/24	05/30
TIME	1720	1750	1820	1850	1915	1940	2000	2025	2045	2110	2135	2200	2225	2255	1506
T(1)	126.20	124.36	123.24	122.49	120.21	119.29	115.85	114.79	114.14	115.61	117.38	119.05	121.61	124.88	184.47
T(2)	129.97	127.94	126.51	125.45	122.77	121.47	116.05	114.00	113.35	114.79	116.97	118.88	121.51	125.01	191.11
T(3)	133.74	131.57	129.94	128.55	125.76	124.09	118.03	112.53	111.92	113.25	115.91	118.37	121.16	124.67	197.94
T(4)	135.88	133.67	132.04	130.41	127.39	125.62	121.40	110.82	110.79	111.37	114.41	117.42	120.55	124.19	201.00
T(5)	137.06	134.93	133.30	131.50	128.41	126.54	123.31	109.32	110.65	109.70	112.09	115.98	119.53	123.72	203.95
T(6)	137.06	134.93	133.43	131.77	128.55	126.68	124.02	108.46	111.85	108.64	110.04	114.31	118.47	122.80	203.95
T(7)	135.67	133.81	132.32	130.82	127.60	125.79	123.55	108.12	113.42	107.78	108.46	112.06	117.07	121.78	201.66
T(8)	133.37	131.67	130.31	129.09	125.86	124.19	122.22	108.77	114.34	107.27	107.44	109.80	115.78	120.79	197.07
T(9)	129.84	128.31	127.26	126.34	123.28	121.81	120.21	110.00	114.41	107.75	107.06	108.09	114.58	119.77	190.34
T(10)	125.32	124.09	123.21	122.70	120.11	118.92	117.76	110.52	113.97	108.50	107.44	107.71	113.83	118.92	181.26
T(11)	120.72	119.63	118.95	118.92	116.80	116.02	115.23	110.00	112.88	108.43	107.68	107.64	113.05	118.06	171.42
TEIL	88.92	89.20	89.61	90.58	90.64	90.95	91.02	91.26	91.13	92.02	92.47	92.92	93.85	95.05	103.81
TEI	95.37	96.44	97.40	99.29	99.70	100.56	101.21	102.03	101.86	102.55	103.58	104.81	110.70	116.37	112.65
TEO	104.81	105.22	106.01	107.25	108.55	109.47	110.80	116.03	111.52	113.98	115.52	117.36	120.36	124.08	124.96
TEOL	103.52	104.51	105.28	106.82	107.53	108.97	110.07	112.22	111.29	113.73	115.43	116.36	119.36	123.00	123.97
TRATIO	0.44	0.47	0.50	0.54	0.54	0.53	0.53	0.51	0.53	0.48	0.48	0.51	0.66	0.76	0.44
QL	37.39	35.84	34.71	33.59	31.53	30.34	27.56	20.88	20.86	21.21	23.10	24.99	27.01	29.39	91.47
Q	501.67	503.22	505.42	503.76	503.03	503.15	510.85	517.54	516.49	518.92	519.18	518.36	516.34	510.09	1934.19
HC	5.02	5.57	6.23	7.50	8.83	10.36	10.67	193.15	124.22	345.90	116.92	53.37	65.67	73.81	10.77
AGRPM	178.52	218.10	256.08	340.12	422.96	508.75	594.46	676.08	635.93	719.93	761.39	839.97	970.38	2958.26	202.75
RER	144.7	183.5	222.1	313.3	398.1	500.1	604.1	728.0	669.4	806.5	896.3	1024.2	1352.8	4744.4	317.6
WLBH	72.9	73.0	72.7	72.6	74.3	74.6	76.7	78.4	77.3	79.9	79.5	82.3	83.9	86.2	193.2
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.01	0.01	0.02	0.03	0.05	0.07	0.10	0.08	0.11	0.13	0.17	0.22	0.74	0.00

TABLE V (Continued)

DATE TIME	05/30 1540	05/30 1606	05/30 1630	05/30 1700	05/30 1730	05/30 1800	05/30 1835	05/30 1906	05/30 2007	05/30 2045	05/30 2117	05/30 2150	06/01 1625	06/01 1700	06/01 1730
T(1)	179.26	175.98	172.10	149.43	156.31	145.55	151.46	146.43	145.99	145.72	145.65	146.16	158.73	166.29	182.30
T(2)	185.14	181.66	177.32	150.24	156.81	143.19	151.80	145.55	145.55	145.69	145.65	146.26	164.25	172.60	188.54
T(3)	191.98	187.97	183.07	151.22	156.78	139.94	150.75	143.36	144.07	144.54	144.88	145.69	169.92	178.66	194.57
T(4)	194.81	190.74	185.67	154.12	158.80	141.29	151.73	141.33	142.78	143.56	143.96	145.01	172.93	181.93	197.10
T(5)	197.67	193.51	188.34	158.16	163.88	144.54	152.64	136.66	139.77	141.16	142.10	143.46	175.41	183.94	197.80
T(6)	197.80	193.67	188.58	161.12	167.80	144.03	154.29	133.98	137.03	139.23	140.28	142.00	175.64	183.77	196.01
T(7)	195.81	191.78	186.91	163.07	169.88	149.60	156.11	132.15	134.21	136.93	138.28	140.24	173.94	181.66	192.14
T(8)	191.61	187.74	183.17	163.84	169.98	150.99	157.69	131.37	132.38	134.55	136.35	138.59	170.42	177.52	186.17
T(9)	185.34	181.87	177.89	162.30	167.57	151.29	157.35	138.89	133.27	132.86	134.62	136.99	165.32	171.59	178.49
T(10)	177.02	174.17	170.99	158.80	162.87	150.38	153.18	139.43	134.89	132.82	133.60	135.84	158.46	163.67	169.01
T(11)	167.90	165.89	163.57	153.65	156.85	146.94	150.24	137.57	134.42	131.16	131.50	133.64	150.89	155.17	159.74
TEIL	103.98	104.18	104.39	106.07	105.93	107.47	107.10	108.74	108.67	109.87	109.70	110.69	102.64	102.16	101.34
TEI	113.23	113.78	114.63	113.23	113.85	113.23	113.03	113.71	114.63	116.65	118.66	122.92	108.92	107.93	105.36
TEO	124.99	125.40	126.12	128.06	127.38	129.38	129.52	131.45	132.06	133.59	134.03	135.69	117.67	116.13	114.36
TEOL	124.28	124.73	125.18	128.56	128.72	130.85	129.81	133.00	131.26	132.69	132.86	134.55	116.94	115.64	114.28
TRATIO	0.46	0.47	0.49	0.32	0.35	0.25	0.26	0.20	0.26	0.30	0.39	0.51	0.44	0.43	0.31
QL	85.64	81.89	77.29	50.92	54.59	41.27	49.07	41.30	42.36	42.93	43.23	44.01	66.19	73.97	87.79
Q	1928.42	1932.18	1942.95	2014.38	2033.42	2042.55	2023.00	2050.12	2049.83	2045.08	2052.38	2028.06	1360.75	1339.37	1328.35
HC	11.85	12.69	14.01	31.62	29.65	53.64	37.78	79.99	62.88	66.21	67.25	73.61	10.01	8.08	6.10
AGRPM	242.99	283.29	344.62	406.26	377.07	445.47	405.88	508.36	592.41	676.13	765.10	892.33	260.00	179.71	99.35
RER	385.6	456.5	565.8	701.9	657.9	804.7	716.9	962.2	1095.8	1314.0	1524.7	1921.2	337.3	224.1	116.6
WLBH	194.1	193.1	194.0	191.0	188.4	189.0	190.0	185.5	184.9	186.3	187.9	188.6	198.6	203.4	208.5
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.01	0.01	0.02	0.03	0.02	0.03	0.02	0.04	0.06	0.08	0.11	0.16	0.01	0.00	0.00

TABLE V (Continued)

DATE TIME	06/01 1800	06/01 1830	06/01 1852	06/01 1921	06/01 1943	06/01 2011	06/01 2030	06/01 2045	06/01 2136	05/30 2045	05/30 2117	05/30 2150	06/01 1625	06/01 1700	06/01 1730
T(1)	172.97	155.40	140.62	132.62	133.13	134.42	136.38	138.38	134.62	145.72	145.65	146.16	158.73	166.29	182.30
T(2)	179.29	160.04	140.79	131.87	133.03	134.49	136.52	138.62	134.38	145.69	145.65	146.26	164.25	172.60	188.54
T(3)	185.47	165.08	140.08	130.14	132.18	134.05	136.21	138.38	132.72	144.54	144.88	145.69	169.92	178.66	194.57
T(4)	188.44	167.94	140.79	128.07	131.26	133.37	135.74	137.91	130.99	143.56	143.96	145.01	172.93	181.93	197.10
T(5)	190.01	169.95	141.70	121.47	129.46	132.01	134.69	137.03	127.77	141.16	142.10	143.46	175.41	183.94	197.80
T(6)	189.44	170.25	142.98	123.17	128.04	130.92	133.71	136.08	125.45	139.23	140.28	142.00	175.64	183.77	196.01
T(7)	186.64	168.78	144.34	122.19	126.34	129.46	132.55	135.10	124.57	136.93	138.28	140.24	173.94	181.66	192.14
T(8)	182.00	165.69	144.71	121.88	124.64	128.11	131.26	133.98	126.27	134.55	136.35	138.59	170.42	177.52	186.17
T(9)	175.38	161.32	143.86	124.64	123.34	126.88	130.28	132.96	128.41	132.86	134.62	136.99	165.32	171.59	178.49
T(10)	166.76	155.47	141.33	126.17	122.97	126.10	129.43	132.15	129.74	132.82	133.60	135.84	158.46	163.67	169.01
T(11)	157.93	149.13	137.64	125.59	122.46	124.54	127.87	130.62	128.61	131.16	131.50	133.64	150.89	155.17	159.74
TEIL	102.64	104.32	105.52	106.27	107.54	108.46	109.32	110.93	106.89	109.87	109.70	110.69	102.64	102.16	101.34
TEI	107.69	111.18	110.15	110.02	112.58	116.82	121.49	124.69	111.04	116.65	118.66	122.92	108.92	107.93	105.36
TEO	116.10	119.65	121.39	123.09	125.34	127.68	130.67	133.25	124.65	133.59	134.03	135.69	117.67	116.13	114.36
TEOL	115.83	119.00	121.16	123.01	124.36	126.68	129.63	132.04	124.62	132.69	132.86	134.55	116.94	115.64	114.28
TRATIO	0.38	0.47	0.30	0.22	0.30	0.46	0.60	0.65	0.23	0.30	0.39	0.51	0.44	0.43	0.31
QL	79.79	62.00	40.91	31.99	34.17	35.63	37.29	38.84	33.98	42.93	43.23	44.01	66.19	73.97	87.79
Q	1315.51	1349.61	1372.43	1359.25	1379.17	1366.96	1374.32	1380.76	1385.61	2045.08	2052.38	2028.06	1360.75	1339.37	1328.35
HC	7.21	11.46	30.48	130.73	67.79	72.38	81.31	86.34	71.95	66.21	67.25	73.61	10.01	8.08	6.10
AGRPM	138.30	340.12	465.60	596.19	759.89	934.76	1090.14	1055.97	594.68	676.13	765.10	892.33	260.00	179.71	99.35
RER	172.7	473.3	669.2	888.7	1199.2	1620.4	2107.0	2211.0	926.6	1314.0	1524.7	1921.2	337.3	224.1	116.6
WLBH	203.4	194.7	194.5	190.8	192.3	190.3	185.1	184.8	182.5	186.3	187.9	188.6	198.6	203.4	208.5
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.02	0.03	0.06	0.10	0.17	0.25	0.26	0.06	0.08	0.11	0.16	0.01	0.00	0.00

TABLE VI

DATA FOR HEAT TRANSFER TESTS WITH GULF HARMONY OIL 151 AND THE 3.831 INCH DIAMETER BLADE

DATE TIME	04/23 1455	04/23 1510	04/23 1527	04/23 1542	04/23 1552	04/23 1610	04/23 1625	04/23 1640	04/23 1708	04/23 1735	04/23 1805	04/23 1832	04/23 1815	04/26 1135	04/26 1148
T(1)	143.36	142.98	144.34	145.69	148.05	147.95	151.80	158.13	159.20	158.90	158.16	169.75	146.40	140.28	142.54
T(2)	148.15	147.54	147.17	152.57	153.31	153.28	157.05	162.83	164.01	163.57	162.94	173.67	151.53	145.99	148.39
T(3)	153.65	152.91	154.69	156.61	158.97	158.97	162.63	167.54	168.64	168.31	167.67	177.18	157.35	152.10	153.01
T(4)	157.25	156.65	158.33	159.57	161.42	161.29	164.25	168.44	169.61	169.21	168.41	177.18	159.30	156.18	158.63
T(5)	159.37	158.90	160.25	161.73	163.61	163.44	166.23	169.58	170.72	170.25	169.55	176.75	162.53	158.16	160.38
T(6)	157.82	157.52	158.36	159.41	160.85	160.58	163.00	165.79	166.86	166.46	165.72	172.10	160.85	157.96	159.84
T(7)	157.59	157.29	158.23	159.37	160.85	160.72	162.70	165.12	166.13	165.62	165.08	170.59	160.31	156.28	158.03
T(8)	153.85	153.58	154.53	155.60	156.95	156.81	158.56	160.75	161.69	161.22	160.65	165.69	156.61	152.30	154.02
T(9)	148.42	148.12	149.06	150.04	151.46	151.29	152.81	154.86	155.77	155.30	154.66	159.67	151.09	146.57	148.19
T(10)	141.73	141.53	142.27	143.02	144.23	144.13	145.48	147.68	155.17	148.05	147.41	152.77	144.07	139.50	140.79
T(11)	135.33	135.33	135.57	136.21	137.33	137.23	138.52	141.19	141.94	141.50	140.79	147.00	137.37	132.35	133.54
TEIL	97.84	97.87	97.05	96.32	95.64	95.46	94.78	94.19	95.05	93.88	94.05	94.09	96.98	92.64	92.37
TEI	102.89	103.44	102.24	101.11	100.04	99.84	98.81	98.02	98.77	97.85	97.54	97.50	101.76	97.50	97.05
TEO	108.89	109.57	107.52	106.35	105.67	105.53	104.50	102.62	103.41	102.58	102.14	99.84	107.07	102.58	102.00
TEOL	109.90	110.11	108.77	107.91	107.06	107.02	106.27	105.64	106.26	105.27	105.39	105.35	108.84	103.66	103.23
TRATIO	0.42	0.46	0.44	0.41	0.39	0.38	0.35	0.33	0.33	0.35	0.31	0.30	0.40	0.44	0.43
QL	53.37	52.89	54.22	55.21	56.69	56.58	58.97	62.42	63.40	63.06	62.39	69.83	54.99	52.52	54.46
Q	1329.97	1370.96	1327.41	1321.96	1320.48	1320.58	1322.66	1320.92	1308.26	1321.98	1322.65	1319.70	1331.76	1318.85	1322.04
HC	9.76	10.38	9.12	8.85	8.45	8.48	8.19	7.71	7.48	7.60	7.76	6.86	10.16	9.41	7.78
AGRPM	298.88	123.71	258.68	217.59	179.28	178.86	139.95	100.44	100.55	100.22	99.84	61.32	217.59	257.70	216.90
RER	370.3	155.1	309.9	252.0	200.9	199.7	151.6	106.1	108.8	104.7	104.2	63.9	259.5	258.3	213.9
WLBH	237.6	237.6	241.7	241.8	240.6	240.6	239.4	239.5	242.1	240.9	242.2	242.2	237.7	258.3	259.9
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.02	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01

TABLE VI (Continued)

DATE	04/26	04/26	04/26	04/26	04/26	04/26	04/26	04/26	04/26	04/26	04/26	04/26	04/26	04/26	04/26
TIME	1245	1310	1325	1345	1400	1419	1435	1447	1505	1530	1545	1605	1625	1645	1701
T(1)	142.24	146.40	150.28	157.93	168.44	174.31	172.56	165.69	158.83	141.39	139.80	139.09	138.38	137.87	136.89
T(2)	148.25	152.30	156.01	163.14	172.26	177.45	176.08	170.25	163.91	146.87	145.01	144.03	142.71	141.50	139.70
T(3)	154.59	158.70	162.06	168.14	175.61	179.73	178.82	174.64	168.88	153.11	151.16	150.04	148.29	146.46	143.80
T(4)	158.46	161.26	164.18	169.51	175.51	179.32	178.66	175.31	169.95	155.84	154.02	152.94	151.22	149.37	147.00
T(5)	160.41	163.78	166.09	170.39	175.08	177.89	177.49	175.44	170.92	159.00	157.49	156.31	154.46	152.94	151.05
T(6)	159.88	162.43	164.38	168.88	172.40	173.97	173.30	171.76	167.90	157.99	156.85	155.43	154.49	153.25	152.00
T(7)	158.06	160.75	162.43	165.45	168.58	171.39	170.89	169.38	165.86	157.15	156.01	155.13	154.12	152.98	151.76
T(8)	154.02	156.41	157.96	160.55	163.44	166.56	165.76	164.21	161.02	153.18	152.30	151.42	150.55	149.70	148.69
T(9)	148.22	150.28	151.66	154.12	157.39	161.05	159.84	157.66	154.69	147.51	146.70	146.06	145.32	144.57	144.00
T(10)	140.79	142.51	143.86	146.40	150.62	155.17	153.45	150.08	147.07	140.58	139.84	139.43	139.23	138.92	138.89
T(11)	133.57	135.06	136.59	139.53	144.98	150.41	155.00	143.66	140.45	133.81	133.27	134.86	133.47	133.67	134.35
TEIL	92.26	92.13	92.16	92.06	90.61	90.30	90.82	91.71	92.09	93.92	94.02	94.19	95.09	95.74	96.46
TEI	97.05	96.06	95.89	95.75	94.13	91.44	92.58	95.37	96.02	99.05	99.80	100.42	102.00	102.41	104.47
TEO	101.86	102.03	101.00	100.73	95.82	92.68	94.20	101.25	100.90	104.13	104.44	104.98	106.73	108.37	109.64
TEOL	103.27	102.94	102.77	102.56	101.10	100.81	101.37	102.52	102.63	104.78	105.15	105.53	107.12	108.43	109.63
TRATIO	0.44	0.36	0.35	0.35	0.34	0.11	0.17	0.34	0.37	0.47	0.52	0.55	0.57	0.53	0.61
QL	54.32	56.55	58.91	63.31	68.39	71.68	71.10	68.21	63.68	52.26	50.84	50.00	48.68	47.27	45.49
Q	1340.06	1319.95	1315.87	1313.18	1308.11	1304.81	1318.80	1347.63	1311.11	1296.96	1325.66	1326.49	1345.70	1348.83	1325.88
HC	9.08	8.68	8.32	8.21	7.59	6.72	6.69	7.11	7.51	9.74	10.60	10.74	12.40	13.42	14.62
AGRPM	216.31	177.62	138.63	98.89	59.76	38.73	47.61	77.34	96.43	255.43	297.56	336.85	420.06	502.47	587.50
RER	213.6	171.7	133.2	94.3	53.9	33.4	42.3	73.3	92.5	268.2	318.3	366.4	483.5	598.9	738.3
WLBH	259.9	258.4	258.4	260.0	258.7	257.2	258.6	258.5	258.4	258.1	259.6	258.0	253.2	248.7	245.7
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.04	0.06	0.09

TABLE VI (Continued)

DATE TIME	04/26 1721	04/26 1740	04/26 1800	04/26 1815	04/26 1830	04/26 1841	04/26 1850	04/26 1900	04/26 1915	04/26 1937	04/27 1550	04/27 1607	04/27 1622	04/27 1642	04/27 1700
T(1)	136.55	135.84	129.46	128.92	129.23	128.14	128.85	130.14	132.01	135.10	185.10	183.90	180.83	177.08	167.94
T(2)	138.35	136.82	128.55	128.58	129.43	128.44	129.16	130.45	131.57	135.20	189.81	188.11	183.00	178.15	167.27
T(3)	140.92	137.94	129.06	127.77	128.58	128.21	128.89	130.28	130.75	136.62	196.14	193.18	185.04	178.59	167.13
T(4)	143.42	139.13	130.79	128.85	128.27	127.70	128.44	129.67	131.60	138.62	199.50	196.54	186.11	178.66	168.41
T(5)	146.33	139.94	132.15	129.77	128.14	126.47	127.19	128.72	132.45	139.50	203.65	200.73	186.84	178.22	168.61
T(6)	147.34	140.48	133.54	131.16	128.72	125.83	125.93	127.56	133.27	139.77	203.95	201.19	189.71	178.69	169.48
T(7)	147.54	141.29	134.86	132.65	129.67	125.66	125.01	126.41	134.18	141.09	201.39	198.73	187.61	179.32	171.36
T(8)	145.59	140.55	135.27	133.30	130.18	125.35	124.67	125.90	134.52	141.12	196.41	193.97	185.27	178.36	171.96
T(9)	141.83	138.62	134.08	132.42	129.63	125.22	124.84	125.83	133.81	139.43	189.84	187.84	181.16	176.11	171.02
T(10)	137.77	136.18	132.72	131.30	128.99	125.42	124.74	125.56	132.99	137.47	182.53	181.43	176.92	173.60	169.72
T(11)	134.01	133.50	130.99	129.80	127.94	124.54	123.82	124.50	131.70	135.33	175.98	175.31	172.23	170.22	167.23
TEIL	97.35	99.07	101.61	102.50	103.40	104.73	105.73	106.68	105.35	103.81	122.77	123.31	124.23	125.22	126.44
TEI	106.22	108.79	111.21	111.86	112.65	115.38	116.99	118.97	114.22	112.75	127.21	128.77	129.72	132.47	134.13
TEO	111.35	113.81	117.33	118.56	119.99	121.90	123.46	125.30	120.53	118.35	135.46	136.51	138.37	140.40	142.43
TEOL	111.56	115.16	116.73	117.69	118.98	120.79	122.39	124.16	119.87	118.51	138.62	139.50	145.99	145.55	142.51
TRATIO	0.62	0.60	0.64	0.62	0.59	0.66	0.68	0.70	0.61	0.61	0.28	0.34	0.25	0.36	0.48
QL	42.83	39.71	33.84	32.52	32.13	31.74	32.24	33.08	34.41	39.34	90.05	87.25	77.68	71.10	62.39
Q	1358.80	1368.16	1355.37	1356.69	1341.97	1342.37	1332.97	1327.71	1328.08	1325.87	1871.77	1874.56	1895.61	1896.86	1920.34
HC	18.43	25.72	41.28	52.11	63.34	83.76	89.53	96.68	48.44	27.54	12.77	13.72	22.67	26.57	33.82
AGRPM	672.53	750.83	837.75	873.75	917.50	978.91	1016.92	1111.60	808.68	719.97	225.92	265.16	306.59	347.55	388.43
RER	901.3	1122.3	1332.9	1429.2	1556.0	1778.5	1943.8	2250.9	1422.6	1210.5	656.5	795.5	1040.0	1202.1	1295.9
WLBH	244.0	249.0	248.8	245.8	248.4	248.2	247.9	249.1	248.3	248.5	235.9	234.4	232.2	232.3	232.7
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.11	0.15	0.19	0.22	0.24	0.29	0.32	0.37	0.17	0.13	0.00	0.01	0.01	0.02	0.02

TABLE VI (Continued)

DATE TIME	04/27 1715	04/27 1730	04/27 1750	04/27 1810	04/27 1822	04/27 1837	04/27 1850	04/27 1900	04/27 1910	04/27 1915	05/14 1445	05/14 1520	05/14 1605	05/14 1640	05/14 1710
T(1)	160.72	157.59	157.56	157.96	157.99	159.20	160.31	161.56	163.10	163.54	170.08	172.70	165.05	160.18	147.85
T(2)	161.39	158.16	158.16	158.53	158.46	159.71	160.75	162.03	163.67	164.04	173.74	177.69	167.64	160.85	147.24
T(3)	160.72	157.86	157.93	158.46	158.46	159.71	160.75	161.99	163.78	164.31	178.96	184.34	171.46	161.26	145.01
T(4)	160.68	157.25	157.52	158.03	158.13	159.47	160.52	161.86	163.71	164.11	183.10	187.04	175.44	161.59	145.35
T(5)	160.25	155.50	155.94	156.81	156.95	158.40	159.51	160.85	162.77	163.20	186.84	192.04	178.96	162.03	146.73
T(6)	161.02	154.76	154.36	155.33	155.50	157.32	158.50	160.04	161.89	162.50	187.84	192.51	180.06	163.04	147.75
T(7)	162.43	154.32	153.08	154.19	154.66	156.21	157.49	159.07	161.02	161.56	185.81	189.94	178.49	163.74	150.28
T(8)	162.94	154.93	152.23	153.28	153.99	155.50	156.81	158.33	160.21	160.85	181.20	185.04	174.61	162.40	151.86
T(9)	162.77	155.10	152.07	153.08	153.78	155.10	156.48	158.03	159.84	160.48	174.81	178.12	168.88	159.81	151.56
T(10)	162.40	155.40	151.76	152.57	153.45	154.83	156.01	157.69	159.51	160.15	167.84	169.88	163.04	156.95	150.65
T(11)	161.02	153.82	150.04	150.95	151.93	153.25	154.76	156.38	158.23	158.93	161.22	162.06	157.45	153.35	148.52
TEIL	127.90	128.78	129.91	131.03	131.77	132.99	134.01	135.67	136.42	137.60	107.95	106.79	106.92	107.37	108.67
TEI	134.34	136.85	138.91	141.52	143.41	145.78	147.91	150.40	152.43	153.88	116.65	114.43	116.20	118.45	120.16
TEO	144.60	145.85	147.50	149.05	150.23	152.06	153.91	156.07	158.09	159.47	124.59	122.10	124.45	125.81	128.74
TEOL	144.07	145.18	146.57	148.19	149.20	151.12	152.91	155.00	157.12	158.19	125.07	123.16	124.08	127.60	127.73
TRATIO	0.40	0.49	0.54	0.61	0.67	0.71	0.74	0.76	0.77	0.79	0.51	0.47	0.54	0.55	0.60
QL	56.09	53.37	53.58	53.98	54.06	55.13	55.96	57.04	58.53	58.86	75.00	78.52	68.33	56.82	44.26
Q	1926.65	1946.27	1949.36	1958.90	1958.82	1930.08	1942.86	1926.94	1925.44	1923.05	1911.39	1905.82	1913.96	1913.52	1942.13
HC	51.70	70.68	74.77	83.89	93.41	99.50	109.83	121.49	123.91	139.31	13.89	13.02	15.82	27.14	49.08
AGRPM	450.59	512.14	597.15	685.86	767.56	855.30	941.48	1018.33	1095.59	1164.48	342.66	261.19	424.90	510.44	635.88
RER	1547.2	1836.7	2236.2	2704.7	3132.9	3681.4	4251.7	4860.7	5502.3	6021.8	688.5	492.5	832.7	1099.2	1399.1
WLBH	232.5	231.0	229.6	226.9	224.4	224.1	225.0	223.5	223.2	223.1	232.8	239.5	236.8	237.5	237.5
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.03	0.04	0.06	0.08	0.10	0.13	0.18	0.21	0.25	0.28	0.02	0.01	0.03	0.05	0.08

TABLE VI (Continued)

DATE TIME	05/14 1745	05/14 1800	05/14 1835	05/14 1855	05/14 1915	05/17 1140	05/17 1528	05/17 1631	05/17 1705	05/17 1748	05/17 1816	05/17 1915	05/17 1937	05/17 2015	05/17 2042
T(1)	142.98	143.39	146.40	146.40	147.92	139.64	140.31	166.90	160.62	155.10	151.36	148.59	147.00	162.06	145.21
T(2)	142.82	143.29	146.60	146.50	148.09	143.80	144.37	171.42	164.75	159.71	156.07	153.31	151.63	166.23	149.43
T(3)	142.38	142.95	146.36	146.33	147.81	148.52	149.23	172.77	168.78	164.61	161.39	158.80	156.88	170.29	154.29
T(4)	141.50	141.80	145.76	145.55	147.21	151.42	152.30	173.44	170.45	167.13	164.41	162.06	160.38	171.93	157.69
T(5)	139.97	140.41	144.71	144.34	146.16	153.75	154.66	172.46	170.42	167.77	165.52	163.57	162.20	172.13	159.67
T(6)	139.06	139.40	143.52	143.05	145.05	153.75	154.79	170.39	168.91	166.76	164.85	163.34	162.13	170.75	159.74
T(7)	138.76	138.92	142.41	141.83	143.80	151.80	153.11	166.90	165.69	163.91	162.40	161.19	160.08	167.70	157.99
T(8)	138.79	138.96	141.77	141.16	143.19	148.52	149.70	162.53	161.49	160.01	158.83	157.49	156.61	163.51	154.56
T(9)	138.92	138.96	141.39	140.82	142.75	143.52	144.71	157.25	155.94	154.49	153.75	152.57	151.56	158.06	149.47
T(10)	138.82	138.89	140.99	140.28	142.34	137.54	138.69	151.39	149.23	147.65	147.07	145.99	145.08	151.59	143.36
T(11)	137.13	137.40	139.36	138.65	140.79	131.77	132.96	146.40	143.66	141.67	140.95	139.80	138.99	146.06	137.64
TEIL	110.93	111.37	116.39	116.05	117.55	95.33	92.95	91.92	92.33	93.19	94.50	94.02	94.36	94.40	95.39
TEI	122.85	123.33	132.06	130.09	133.59	102.03	102.27	95.85	98.26	99.67	101.59	102.03	103.44	100.73	104.81
TEO	131.59	132.03	138.54	137.29	140.06	109.50	111.35	104.09	107.21	109.33	111.52	112.72	113.91	110.02	114.67
TEOL	130.52	131.13	137.43	136.35	138.96	110.95	110.85	109.07	109.81	111.04	113.58	113.34	113.56	112.92	115.07
TRATIO	0.61	0.61	0.74	0.69	0.75	0.43	0.52	0.23	0.34	0.36	0.37	0.41	0.47	0.34	0.48
QL	41.42	41.64	44.56	44.41	45.64	48.84	49.51	66.62	64.10	61.34	59.11	57.20	55.85	65.34	53.71
Q	1944.97	1961.64	1962.05	1966.32	1967.14	957.30	959.53	943.88	960.84	971.32	973.55	975.46	975.34	961.06	976.55
HC	77.56	79.88	102.29	92.20	103.59	8.65	8.49	5.64	5.85	6.15	6.58	7.00	7.25	6.07	8.07
AGRPM	762.46	760.90	1075.94	927.70	1073.61	217.47	217.17	43.37	62.01	82.01	100.79	120.58	139.51	60.74	178.62
RER	1822.2	1849.1	3216.1	2665.4	3348.4	272.8	272.7	48.2	72.3	100.0	133.2	159.4	188.6	78.3	253.8
WL8H	238.4	235.7	244.1	237.5	243.9	131.7	115.0	113.9	113.8	112.8	105.8	104.8	105.5	107.1	103.2
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.12	0.12	0.27	0.19	0.27	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE VI (Continued)

DATE TIME	05/17 2100	05/17 2130	05/17 2150	05/17 2213	05/17 2230	05/17 2245	05/17 2300	05/17 2315	05/17 2330	05/17 1748	05/17 1816	05/17 1915	05/17 1937	05/17 2015	05/17 2042
T(1)	143.86	141.77	143.19	139.16	141.43	138.15	131.84	132.28	132.99	155.10	151.36	148.59	147.00	162.06	145.21
T(2)	147.81	144.37	146.40	140.08	143.09	138.59	131.57	132.35	133.03	159.71	156.07	153.31	151.63	166.23	149.43
T(3)	152.44	147.95	150.55	141.46	145.69	139.40	131.13	132.15	132.69	164.61	161.39	158.80	156.88	170.29	154.29
T(4)	155.81	150.95	153.51	143.12	148.36	140.48	131.60	131.60	132.01	167.13	164.41	162.06	160.38	171.93	157.69
T(5)	157.82	153.31	155.84	145.15	150.99	141.16	132.01	130.48	130.79	167.77	165.52	163.57	162.20	172.13	159.67
T(6)	158.06	154.36	156.58	147.41	152.60	141.29	132.62	129.16	129.40	166.76	164.85	163.34	162.13	170.75	159.74
T(7)	156.31	153.31	154.96	147.58	152.23	141.67	133.91	128.14	128.72	163.91	162.40	161.19	160.08	167.70	157.99
T(8)	152.98	150.38	151.73	145.65	149.87	140.62	133.64	127.80	128.31	160.01	158.83	157.49	156.61	163.51	154.56
T(9)	147.95	145.79	146.87	142.38	146.03	138.11	132.35	127.77	128.55	154.49	153.75	152.57	151.56	158.06	149.47
T(10)	142.00	146.70	141.29	139.13	141.73	135.88	131.26	127.56	128.55	147.65	147.07	145.99	145.08	151.59	143.36
T(11)	136.35	135.98	136.21	136.08	137.91	133.71	129.97	126.68	127.53	141.67	140.95	139.80	138.99	146.06	137.64
TEIL	95.09	95.53	95.81	96.08	95.84	96.01	96.50	97.49	98.69	93.19	94.50	94.02	94.36	94.40	95.39
TEI	105.57	108.24	108.07	112.38	111.56	114.39	115.96	121.73	121.45	99.67	101.59	102.03	103.44	100.73	104.81
TEO	114.77	116.92	116.27	119.78	118.76	121.08	123.97	128.36	128.43	109.33	111.52	112.72	113.91	110.02	114.67
TEOL	114.38	116.65	117.82	120.67	119.00	120.79	123.11	127.36	127.53	111.04	113.58	113.34	113.56	112.92	115.07
TRATIO	0.54	0.60	0.56	0.66	0.68	0.74	0.73	0.81	0.79	0.36	0.37	0.41	0.47	0.34	0.48
QL	52.23	48.48	50.45	42.61	46.51	40.69	34.41	34.41	34.69	61.34	59.11	57.20	55.85	65.34	53.71
Q	978.03	981.78	1051.69	1065.90	1062.00	1069.40	1075.68	1086.82	1082.54	971.32	973.55	975.46	975.34	961.06	976.55
HC	8.55	11.32	11.45	21.76	15.35	23.25	49.90	93.34	88.06	6.15	6.58	7.00	7.25	6.07	8.07
AGRPM	218.10	379.63	298.58	548.09	465.48	630.27	756.37	949.06	875.54	82.01	100.79	120.58	139.51	60.74	178.62
RER	308.2	581.8	468.0	959.1	779.6	1132.0	1449.5	2109.3	1946.5	100.0	133.2	159.4	188.6	78.3	253.8
WLBH	105.5	103.3	103.0	103.8	104.7	106.6	110.0	114.4	111.1	112.8	105.8	104.8	105.5	107.1	103.2
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.03	0.02	0.06	0.04	0.09	0.15	0.26	0.21	0.00	0.00	0.00	0.00	0.00	0.00

TABLE VII

DATA FOR HEAT TRANSFER TESTS WITH GULF HARMONY OIL 151 AND THE 4.000 INCH DIAMETER BLADE

DATE TIME	09/15 1120	09/15 1155	09/15 1220	09/15 1245	09/15 1310	09/15 1340	09/15 1400	09/15 1425	09/15 1455	09/15 1525	09/15 1540	09/15 1600	09/15 1635	09/15 1650	09/15 1720
T(1)	104.53	113.70	106.45	107.16	106.10	108.09	107.85	104.01	108.81	104.05	103.05	102.81	114.41	119.70	108.46
T(2)	112.43	120.96	112.57	113.63	112.02	114.89	116.29	111.75	118.17	111.85	110.69	110.28	124.36	116.67	117.86
T(3)	114.62	122.60	114.58	115.98	113.93	118.88	118.57	115.27	120.25	113.73	112.36	111.92	125.22	118.88	119.90
T(4)	117.28	123.68	116.53	116.49	115.98	119.22	120.38	115.57	121.81	115.64	114.31	113.87	125.69	120.55	121.44
T(5)	117.38	123.65	117.38	118.88	117.31	119.73	120.82	116.15	121.57	116.29	115.10	115.10	125.39	120.82	121.64
T(6)	116.56	121.98	116.67	117.72	114.82	117.21	118.23	114.65	119.09	114.58	113.63	113.25	122.53	118.71	119.56
T(7)	114.75	120.38	114.82	116.12	114.41	116.70	117.82	114.00	118.68	113.97	113.11	112.77	121.57	117.72	118.57
T(8)	112.43	117.86	112.43	113.63	112.06	114.24	115.33	111.78	116.26	111.71	111.00	110.65	118.95	115.16	116.09
T(9)	109.70	115.64	110.89	112.02	110.69	112.57	113.59	110.31	114.28	110.21	109.49	109.11	116.87	113.22	114.11
T(10)	109.35	113.25	110.04	110.55	109.53	111.10	111.95	109.15	112.40	109.15	108.43	108.12	114.11	111.47	112.06
T(11)	107.61	110.86	108.09	108.77	107.92	109.18	109.83	107.75	110.38	107.78	107.23	108.50	111.85	109.49	109.87
TEIL	95.26	94.91	95.95	95.77	96.15	95.95	95.91	96.46	95.43	95.98	95.95	95.91	94.91	95.33	94.23
TEI	96.88	96.23	97.60	97.05	97.91	97.16	97.23	97.91	96.95	97.30	97.30	97.30	95.71	96.26	95.20
TEO	98.26	96.44	99.97	98.33	98.50	98.33	98.29	101.04	97.23	100.35	100.49	100.66	96.26	97.26	95.54
TEOL	98.82	98.28	99.58	99.30	99.75	99.41	99.35	100.11	98.84	99.61	99.66	99.67	98.28	98.65	97.66
TRATIO	0.46	0.39	0.46	0.36	0.49	0.35	0.38	0.40	0.45	0.36	0.36	0.37	0.24	0.28	0.28
QL	24.90	29.06	24.43	24.41	24.08	26.15	26.90	23.83	27.83	23.87	23.03	22.76	30.39	27.01	27.58
Q	814.21	810.84	830.00	818.97	819.29	815.10	814.35	817.42	814.77	825.70	824.40	828.17	810.86	802.50	825.49
HC	15.21	12.16	18.30	18.88	14.52	15.12	11.71	21.55	11.51	17.04	18.87	18.36	10.50	12.00	11.83
AGRPM	148.17	55.75	170.06	132.38	189.41	114.05	94.70	210.36	77.08	189.41	229.13	248.07	41.55	86.30	70.50
RER	143.3	52.7	169.1	129.8	189.9	112.2	93.1	212.7	74.6	187.7	227.3	246.1	39.0	82.4	64.8
WLBH	507.9	515.2	512.4	512.5	516.0	514.9	514.9	512.2	512.6	514.8	514.8	514.8	515.2	517.6	515.4
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.01	0.00	0.01	0.01	0.02	0.01	0.00	0.02	0.00	0.02	0.03	0.03	0.00	0.00	0.00

TABLE VII (Continued)

DATE TIME	09/15 1745	09/15 1800	09/15 1820	09/15 1845	09/15 1900	09/15 1915	09/15 1935	09/15 1955	09/15 2012	09/15 2025	09/15 2040	09/15 2050	09/15 2100	09/15 2105	10/08 1230
T(1)	109.32	101.96	101.82	104.18	104.83	105.38	106.21	106.27	106.79	106.62	104.01	104.70	108.88	109.90	141.67
T(2)	118.88	109.01	109.01	109.70	111.20	111.54	113.76	114.11	114.41	114.31	115.81	116.36	119.70	120.45	145.89
T(3)	120.76	110.55	110.65	111.85	114.11	114.14	116.15	116.84	116.15	116.15	117.31	117.89	120.72	121.44	147.17
T(4)	122.08	112.57	112.74	114.62	117.21	117.18	119.02	119.70	118.40	118.54	119.02	119.56	121.57	121.95	148.36
T(5)	122.12	113.80	114.28	116.84	119.26	119.29	120.62	120.62	119.60	119.87	119.73	120.38	122.15	122.46	149.03
T(6)	119.90	112.60	113.46	116.02	118.57	118.54	120.18	120.89	119.77	119.90	120.25	121.10	122.12	122.12	149.03
T(7)	118.75	111.95	112.77	115.57	118.78	118.64	120.25	120.76	119.70	119.90	120.04	120.72	121.64	121.85	147.75
T(8)	116.12	109.56	109.97	111.95	115.68	115.16	118.23	118.57	118.03	118.00	118.40	119.05	120.72	121.23	146.19
T(9)	114.00	108.09	108.09	109.18	111.92	111.68	115.10	115.10	115.33	115.30	116.15	118.54	119.77	120.42	144.84
T(10)	111.92	108.64	106.89	107.61	109.32	109.35	111.78	111.88	112.88	112.64	114.58	115.16	119.19	119.94	144.10
T(11)	109.87	105.69	105.59	106.34	107.78	107.99	109.87	110.00	111.34	111.17	113.29	113.80	118.17	118.54	142.10
TEIL	94.09	94.95	95.12	95.95	96.80	97.15	98.18	98.66	99.42	99.38	100.31	100.93	102.64	102.68	129.57
TEI	95.06	95.95	96.40	97.23	98.33	98.64	100.01	100.22	101.97	101.55	104.54	104.81	109.03	109.26	133.96
TEO	95.06	99.49	100.18	101.07	102.31	102.58	104.47	104.30	106.25	105.98	108.27	108.61	112.14	112.14	137.25
TEOL	97.48	98.83	99.16	100.15	101.55	101.45	103.16	103.42	104.98	104.74	106.77	107.05	111.06	111.44	133.45
TRATIO	0.29	0.26	0.32	0.30	0.32	0.35	0.37	0.33	0.46	0.41	0.65	0.63	0.76	0.75	1.13
QL	28.01	21.95	22.06	23.23	24.86	24.84	26.02	26.46	25.62	25.71	26.02	26.37	27.67	27.92	46.51
Q	825.06	835.99	831.01	821.50	819.87	819.89	823.55	823.11	813.25	823.86	821.41	821.06	819.76	819.51	827.48
HC	11.59	20.36	21.01	17.56	15.89	15.93	17.05	18.44	22.77	21.73	28.45	28.44	34.01	34.07	25.60
AGRPM	70.50	285.13	325.87	366.60	525.46	406.31	525.46	497.97	604.89	574.34	702.65	678.21	861.51	861.51	305.50
RER	64.4	272.2	315.5	367.6	552.7	428.1	586.9	561.0	722.7	678.8	903.8	881.1	1289.3	1303.7	945.2
WLBH	521.6	521.2	518.0	517.7	517.2	519.1	518.5	518.5	513.1	513.2	512.5	512.4	493.7	493.6	470.7
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.04	0.05	0.08	0.13	0.09	0.15	0.13	0.20	0.18	0.29	0.26	0.42	0.42	0.02

TABLE VII (Continued)

DATE	10/08	10/08	10/08	10/08	10/08	10/08	10/08	10/08	10/08	10/08	10/08	10/09	10/09	10/09	10/09
TIME	1310	1345	1410	1437	1455	1525	1600	1625	1640	1715	1735	1410	1430	1453	1720
T(1)	140.58	141.12	141.39	142.27	143.12	147.85	152.81	140.24	146.36	147.68	146.70	147.21	149.37	152.50	157.99
T(2)	146.53	147.07	147.68	148.89	150.14	156.11	160.89	147.17	147.68	149.03	147.58	147.88	149.91	152.77	158.36
T(3)	147.85	148.39	149.03	150.41	152.13	158.50	162.67	148.39	149.10	150.78	148.36	148.15	150.11	152.98	158.36
T(4)	148.93	149.43	150.04	151.42	153.11	159.71	163.07	149.57	150.18	151.39	148.59	148.42	150.38	153.04	158.46
T(5)	149.57	150.04	150.45	151.63	153.48	159.74	162.83	150.14	150.78	151.90	148.73	148.56	150.28	152.94	158.43
T(6)	149.57	149.91	150.18	151.29	152.94	158.87	161.56	150.21	150.72	151.59	148.36	147.88	149.57	152.13	157.52
T(7)	148.63	148.76	148.96	150.08	151.42	158.50	159.47	149.23	149.50	150.38	147.88	147.41	149.27	151.66	157.29
T(8)	146.90	147.07	147.51	148.42	149.70	154.46	156.92	147.58	147.75	148.89	147.54	146.90	148.93	151.42	156.85
T(9)	145.59	145.82	146.19	147.17	148.09	152.13	154.29	146.23	146.53	147.41	147.07	146.57	148.69	151.12	156.51
T(10)	144.54	144.71	145.05	145.86	146.53	149.57	151.39	145.15	145.45	146.13	146.57	146.40	148.22	150.78	156.61
T(11)	142.85	143.19	143.32	143.86	144.47	146.90	148.42	143.46	143.63	144.20	145.21	145.48	147.34	149.87	155.33
TEIL	130.41	130.99	131.30	131.26	130.79	130.28	129.91	131.43	131.53	131.60	131.50	133.50	136.18	139.09	145.48
TEI	134.78	135.18	135.35	135.83	135.63	135.18	134.81	136.00	136.17	136.34	138.37	140.40	143.95	147.03	153.61
TEO	138.20	138.40	138.57	138.95	138.54	135.66	134.68	139.42	139.72	139.39	140.74	142.57	146.01	149.43	156.67
TEOL	137.26	134.60	134.86	134.75	134.18	133.58	133.24	138.28	135.12	135.12	139.47	141.33	144.71	148.25	155.30
TRATIO	0.64	1.16	1.14	1.31	1.43	1.49	1.47	0.67	1.29	1.35	0.86	0.88	0.91	0.87	0.83
QL	46.94	47.32	47.78	48.84	50.13	55.31	58.01	47.42	47.89	48.81	46.68	46.56	48.04	50.08	54.32
Q	825.68	825.30	827.58	826.52	825.23	806.33	817.35	827.94	827.48	826.55	828.68	822.52	842.15	840.11	821.04
HC	30.12	25.74	25.10	23.11	19.99	13.32	12.40	31.29	25.82	24.57	42.49	52.23	67.96	77.81	103.25
AGRPM	305.50	259.06	218.94	179.63	139.31	62.32	35.90	296.33	238.29	179.02	418.53	549.90	672.10	794.30	953.16
RER	1020.3	828.5	704.7	579.9	444.2	195.7	111.6	1020.0	777.0	584.8	1505.9	2084.3	2791.1	3599.5	5127.3
WLBH	496.0	494.8	494.7	500.6	500.7	500.9	501.0	494.2	495.2	495.2	493.9	488.7	487.7	488.8	486.6
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.02	0.01	0.01	0.05	0.08	0.14	0.19	0.27

TABLE VII (Continued)

DATE TIME	02/18 1620	02/18 1632	02/18 1650	02/18 1705	02/18 1725	02/18 1742	02/18 1755	02/18 1810	02/18 1828	02/18 1845	02/18 1900	02/18 1915	02/18 1925	02/18 1935	02/18 1955
T(1)	143.63	143.63	143.96	144.27	142.10	142.04	141.97	142.51	143.36	143.49	142.61	142.51	142.21	32.37	146.03
T(2)	147.44	147.41	147.58	147.61	144.54	143.86	143.56	144.00	144.51	144.47	143.32	142.88	142.95	32.37	148.29
T(3)	151.80	151.73	151.90	152.13	148.93	146.84	146.19	146.06	145.92	145.01	143.66	143.19	142.98	32.37	152.44
T(4)	156.31	153.14	155.13	155.50	152.34	149.23	154.90	147.54	146.57	145.38	143.96	143.49	143.46	143.46	156.18
T(5)	158.97	158.87	159.64	159.71	155.84	151.76	149.74	148.29	146.43	144.67	143.36	142.82	142.75	142.78	159.37
T(6)	159.84	159.71	160.95	161.05	159.20	152.23	150.11	148.42	146.26	144.54	143.15	142.48	142.21	142.17	161.02
T(7)	157.66	157.62	159.00	159.57	155.91	150.78	148.96	147.51	145.65	144.03	142.65	141.53	141.36	141.19	159.34
T(8)	153.08	152.91	155.00	155.03	152.34	147.71	146.23	145.18	145.89	143.49	142.31	141.29	140.82	32.37	155.91
T(9)	146.57	146.19	149.60	149.64	147.61	143.69	142.51	142.27	142.68	142.98	142.21	141.09	140.65	32.37	150.92
T(10)	139.97	139.60	142.78	142.98	141.83	139.06	138.62	139.60	141.16	142.17	142.14	140.85	140.31	32.37	145.38
T(11)	134.42	134.18	136.69	136.89	136.59	134.89	135.13	136.72	138.55	139.91	140.08	139.94	139.09	32.37	140.41
TEIL	106.27	106.31	108.64	107.13	108.33	109.01	109.35	110.14	110.86	112.06	112.74	113.52	114.31	114.79	111.85
TEI	107.35	107.42	108.37	108.55	109.74	110.87	111.86	114.63	117.29	119.31	120.64	122.14	123.43	124.28	113.03
TEO	116.92	117.12	118.11	118.11	119.51	120.40	120.94	121.93	123.12	124.35	125.20	126.32	127.27	128.09	122.54
TEOL	117.85	117.96	120.38	118.94	120.27	121.10	121.69	121.81	123.00	124.30	124.67	125.52	126.41	127.19	123.42
TRATIO	0.09	0.10	0.00	0.12	0.12	0.15	0.20	0.38	0.53	0.59	0.66	0.72	0.75	0.77	0.10
QL	52.63	50.16	51.70	51.99	49.54	47.17	51.52	45.90	45.16	44.28	43.23	42.88	42.86	42.86	52.52
Q	2078.78	2091.05	2085.25	2100.36	2087.42	2089.79	2081.18	2091.06	2086.24	2050.64	2056.76	2076.61	2076.64	2073.23	2052.98
HC	21.62	25.42	24.43	23.91	28.75	30.59	22.46	36.05	41.18	46.39	51.28	55.89	58.52	-183.32	25.90
AGRPM	339.10	339.10	378.82	378.82	415.48	458.25	497.97	543.79	583.50	626.27	662.93	702.65	739.31	775.97	381.88
RER	574.8	576.7	685.3	666.5	762.1	866.6	964.3	1090.1	1235.2	1391.5	1506.2	1650.5	1792.1	1927.3	776.3
WLBH	388.0	388.0	387.4	387.7	387.4	387.2	387.0	387.0	386.7	386.4	386.3	386.1	385.9	385.7	386.6
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.03	0.03	0.04	0.04	0.05	0.06	0.09	0.11	0.12	0.14	0.16	0.19	0.21	0.23	0.04

TABLE VII (Continued)

DATE TIME	02/18 2035	02/18 2050	02/18 2105	02/18 2108	02/18 2122	02/18 2135	02/18 2147	02/18 2159	02/18 2213	02/18 2230	02/18 2245	02/18 2250	02/18 2305	02/20 1300	02/20 1430
T(1)	146.57	146.26	145.45	144.74	144.67	144.84	144.64	145.21	145.01	144.47	143.80	143.56	143.83	167.23	169.48
T(2)	150.14	149.40	147.98	146.70	146.50	146.43	149.30	146.90	146.13	145.25	144.57	144.20	144.67	168.21	170.15
T(3)	156.38	155.33	151.96	149.43	148.86	148.39	147.41	149.06	147.00	145.72	144.84	144.37	144.81	168.61	170.29
T(4)	161.52	160.68	156.28	152.07	150.99	149.87	148.19	150.72	147.17	145.69	144.91	144.51	144.84	168.71	169.88
T(5)	165.22	164.35	159.07	153.92	152.27	150.45	148.19	151.63	146.87	145.42	144.54	144.13	144.47	168.07	169.55
T(6)	166.09	165.96	160.48	154.15	152.74	150.72	148.19	151.76	146.70	145.18	144.30	143.56	144.03	167.54	169.61
T(7)	163.74	163.47	158.80	153.18	151.76	149.94	147.75	150.92	146.23	144.57	143.49	142.82	143.02	167.13	168.88
T(8)	158.63	159.14	155.03	150.08	148.89	147.41	145.89	148.52	145.38	144.23	142.98	142.21	142.17	166.56	167.90
T(9)	152.20	153.28	149.97	146.13	145.01	144.20	144.07	145.05	144.67	144.17	142.85	141.77	141.94	166.23	167.10
T(10)	145.08	146.03	143.56	142.48	140.62	141.50	142.31	141.83	144.07	143.90	142.68	141.87	141.67	165.79	166.09
T(11)	139.23	140.11	138.35	136.69	136.93	138.59	139.84	138.76	141.43	142.07	141.29	140.28	140.08	164.04	163.88
TEIL	108.81	109.11	109.70	110.00	110.07	110.31	110.72	110.72	111.58	111.88	112.53	113.22	114.11	142.51	142.78
TEI	110.29	110.98	111.69	112.48	113.44	116.58	118.45	116.10	120.50	122.14	123.80	125.40	126.70	152.93	151.79
TEO	121.56	122.07	122.68	123.60	124.11	124.48	125.13	124.76	126.25	127.00	127.78	129.07	130.60	157.04	157.28
TEOL	122.82	123.06	123.98	124.44	124.69	124.30	125.35	124.81	126.20	126.44	127.02	128.21	129.60	156.34	156.81
TRATIO	0.11	0.13	0.14	0.17	0.23	0.45	0.53	0.38	0.61	0.70	0.78	0.81	0.81	0.75	0.64
QL	56.77	56.09	52.60	49.33	48.50	47.66	46.38	48.30	45.62	44.51	43.93	43.63	43.88	62.64	63.62
Q	2082.32	2052.81	2070.31	2056.17	2045.99	2046.84	2031.65	2040.70	2045.49	2044.49	2045.07	2066.11	2065.86	1206.37	1209.67
HC	20.42	21.11	25.32	29.72	32.24	35.49	40.48	33.96	45.85	50.98	55.66	61.08	65.48	45.35	43.85
AGRPM	302.44	342.16	381.88	421.59	464.36	507.13	546.85	484.73	588.60	629.33	668.03	727.09	782.08	303.97	263.75
RER	588.5	674.3	773.1	869.2	972.8	1092.6	1228.7	1049.2	1375.8	1504.8	1645.2	1864.1	2087.5	1651.9	1429.2
WLBH	315.7	315.6	315.5	315.4	315.3	315.4	315.2	315.3	315.0	315.0	314.9	314.6	314.3	179.6	177.3
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.02	0.03	0.04	0.05	0.07	0.08	0.10	0.08	0.12	0.14	0.16	0.20	0.23	0.01	0.01

TABLE VII (Continued)

DATE TIME	02/20 1505	02/20 1520	02/20 1535	02/20 1555	02/20 1610	02/20 1622	02/20 1635	02/20 1647	02/20 1702	02/20 1714	02/20 1725	02/20 1735	02/20 1740	02/20 1800	02/20 1810
T(1)	169.51	170.75	168.98	168.54	168.11	168.00	167.54	167.33	167.20	167.47	168.07	168.98	170.79	171.76	172.80
T(2)	170.65	172.16	170.22	169.41	168.88	168.94	168.14	167.77	167.54	167.80	168.41	169.21	170.89	172.06	173.10
T(3)	171.83	173.97	171.06	169.88	169.11	168.91	168.37	167.87	167.64	167.80	168.31	169.21	170.89	172.06	173.10
T(4)	172.46	175.31	171.39	169.95	169.11	168.91	168.27	167.77	167.64	167.80	168.14	169.15	170.92	171.76	172.93
T(5)	172.60	176.28	171.02	169.41	168.64	168.44	167.87	167.20	167.03	167.07	167.54	168.47	170.25	171.06	172.60
T(6)	172.46	176.01	170.75	169.01	168.04	167.90	167.47	166.73	166.56	166.56	167.10	168.07	169.75	170.75	171.83
T(7)	171.39	174.71	169.88	168.54	167.57	167.43	166.93	166.39	166.19	166.23	166.76	167.74	169.38	170.29	171.59
T(8)	168.98	171.46	168.58	168.07	167.13	166.86	166.53	165.89	165.89	165.86	166.43	167.33	168.94	170.08	171.16
T(9)	167.13	167.74	168.94	167.57	166.80	166.60	166.19	165.52	165.42	165.55	166.13	167.03	168.61	169.75	170.82
T(10)	165.59	164.92	166.23	167.00	166.43	166.19	165.76	165.05	165.12	165.29	165.89	166.66	168.41	169.41	170.55
T(11)	163.10	161.96	163.91	165.19	165.05	164.78	164.38	163.78	164.01	164.25	164.88	165.66	167.54	168.54	169.72
TEIL	143.05	143.49	143.80	144.00	144.03	144.07	144.17	144.44	144.67	145.08	146.16	146.80	148.22	148.96	150.04
TEI	150.37	147.87	152.06	153.88	155.22	155.49	156.07	156.54	157.24	158.15	159.30	160.78	163.00	164.34	165.82
TEO	157.75	158.12	158.29	158.59	158.79	158.99	159.43	160.00	161.01	162.06	163.20	164.71	166.93	168.37	169.88
TEOL	157.52	157.52	157.86	157.82	158.06	158.30	158.56	159.17	160.18	161.09	162.30	163.71	165.89	167.37	168.81
TRATIO	0.51	0.31	0.59	0.71	0.80	0.80	0.83	0.82	0.81	0.82	0.81	0.83	0.84	0.84	0.84
QL	65.79	68.21	64.89	63.68	62.98	62.81	62.28	61.86	61.75	61.89	62.17	63.01	64.49	65.20	66.19
Q	1217.74	1229.56	1167.86	1170.69	1174.62	1173.17	1174.69	1172.50	1172.61	1172.48	1172.20	1225.48	1205.16	1197.90	1196.91
HC	34.27	26.55	37.77	44.41	49.57	51.68	57.48	64.18	71.92	79.58	90.29	101.15	105.37	120.99	118.76
AGRPM	223.35	183.30	243.64	283.68	324.85	345.83	387.37	452.14	513.24	578.92	639.51	704.18	769.86	830.96	895.11
RER	1208.4	970.1	1344.8	1590.2	1849.2	1980.3	2238.4	2647.5	3069.9	3537.6	4017.7	4573.6	5257.9	5861.6	6523.5
WLBH	175.7	175.7	175.7	175.7	175.7	175.6	175.6	175.5	175.4	175.3	175.2	175.0	174.8	174.6	174.4
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.01	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.07	0.09	0.11	0.13	0.16	0.19

TABLE VII (Continued)

DATE TIME	06/27 1220	06/27 1245	06/27 1314	06/27 1340	06/27 1403	06/27 1425	06/27 1455	06/27 1528	06/27 1555	06/27 1630	06/27 1700	06/27 1730	07/04 1135	07/04 1200	07/04 1230
T(1)	158.97	161.09	162.50	158.03	154.56	151.83	150.62	151.26	152.30	155.81	159.71	163.37	125.69	125.56	126.58
T(2)	163.88	165.76	164.85	162.57	157.66	152.81	151.29	151.90	152.87	156.34	160.08	163.78	127.39	127.05	128.27
T(3)	170.39	170.59	165.99	168.94	162.87	154.32	151.83	152.07	153.14	156.48	160.28	163.78	129.60	129.26	130.11
T(4)	172.93	171.22	165.89	171.89	166.60	155.33	152.13	152.07	152.94	156.51	160.35	163.88	130.62	130.65	130.11
T(5)	176.31	171.69	164.08	175.78	171.49	156.18	151.86	150.95	151.96	155.43	159.17	162.73	130.82	130.75	130.11
T(6)	175.48	169.48	163.54	175.18	172.90	156.55	151.36	149.94	150.65	154.12	157.99	161.52	130.31	130.41	129.67
T(7)	171.49	164.68	162.03	171.26	171.89	155.43	149.97	148.02	148.09	151.96	156.14	159.74	128.72	129.26	128.24
T(8)	166.09	160.18	161.15	165.86	169.88	153.14	147.58	144.71	145.72	150.08	154.66	158.33	127.77	128.00	126.58
T(9)	159.17	155.97	159.71	158.83	163.98	148.12	143.52	141.19	144.34	149.06	153.78	157.49	124.84	124.88	124.47
T(10)	150.28	150.55	155.03	150.11	156.18	139.60	137.81	138.18	143.09	148.19	152.98	156.61	119.56	119.60	120.11
T(11)	139.94	142.10	147.31	139.80	142.98	132.82	132.52	134.86	141.12	146.26	151.12	154.90	113.63	113.73	114.96
TEIL	114.89	114.92	114.45	114.89	115.20	115.98	115.98	116.97	118.13	120.42	122.97	124.67	100.55	100.69	101.41
TEI	115.72	115.76	115.25	115.69	116.58	119.34	122.75	125.64	132.44	137.79	143.11	147.97	101.55	101.76	102.38
TEO	135.52	135.15	135.15	135.18	134.98	137.35	137.86	139.72	142.16	146.39	151.35	156.20	114.53	114.87	115.04
TEOL	136.36	136.30	135.79	136.29	136.97	138.41	138.90	138.82	141.09	145.48	150.45	155.20	114.72	114.75	115.27
TRATIO	0.04	0.04	0.04	0.04	0.06	0.15	0.30	0.40	0.62	0.69	0.73	0.76	0.07	0.08	0.07
QL	66.19	64.75	60.31	65.31	60.89	51.86	49.38	49.33	50.00	52.78	55.82	58.67	33.73	33.75	33.38
Q	2105.36	2082.84	2091.53	2097.70	2090.95	2070.57	2073.05	2073.10	2097.58	2102.51	2141.70	2131.87	1313.00	1312.98	1311.67
HC	21.11	22.87	29.18	21.23	25.29	43.30	55.15	59.42	72.20	78.38	88.94	98.57	30.04	29.83	34.04
AGRPM	133.17	100.01	61.59	136.98	175.47	253.12	334.29	454.73	574.09	692.66	845.37	1001.74	229.36	228.58	192.38
RER	365.7	274.4	166.5	375.5	491.9	750.3	1036.3	1450.3	2042.3	2801.0	3903.0	5216.9	345.3	345.2	296.1
WLBH	199.8	198.9	200.8	199.8	197.9	194.1	194.0	194.0	193.7	188.9	190.0	185.3	205.4	206.4	206.3
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.07	0.12	0.18	0.27	0.40	0.02	0.02	0.02

TABLE VIII

DATA FOR HEAT TRANSFER TESTS WITH GULF HARMONY OIL 151 AND THE 4.039 INCH DIAMETER BLADE

DATE TIME	07/04 1300	07/04 1330	07/04 1400	07/04 1430	07/04 1500	07/04 1530	07/04 1600	07/04 1645	07/04 1715	07/04 1755	07/05 1100	07/05 1130	07/05 1200	07/05 1225	07/05 1255
T(1)	127.70	128.99	131.64	133.50	135.71	163.41	157.52	164.21	139.03	133.37	174.77	174.27	174.10	174.27	174.07
T(2)	129.33	130.24	132.49	134.25	136.18	165.42	158.73	165.89	139.36	133.74	175.81	175.11	174.84	174.98	174.57
T(3)	130.48	131.26	133.20	135.10	137.16	166.23	159.54	166.93	139.80	133.54	175.95	175.28	175.11	175.28	174.74
T(4)	131.26	131.84	133.06	134.59	137.26	165.45	159.41	166.33	139.26	133.94	175.51	175.14	174.81	174.98	174.51
T(5)	131.23	130.99	131.77	134.08	137.47	162.97	158.19	164.08	139.23	133.16	173.84	173.47	173.27	173.40	174.47
T(6)	130.52	129.60	131.40	133.74	137.40	159.54	156.44	160.78	140.14	133.33	170.89	170.22	169.92	170.29	170.02
T(7)	127.97	127.39	131.09	133.33	137.91	155.00	153.45	156.48	139.50	132.49	169.41	168.21	167.77	168.37	168.37
T(8)	126.27	126.75	130.99	132.15	136.55	149.77	149.60	151.32	138.82	131.98	165.12	164.41	165.19	166.02	166.43
T(9)	124.88	126.34	130.28	131.23	134.69	144.20	145.01	145.76	137.20	131.30	161.19	161.76	163.74	164.85	165.35
T(10)	121.61	123.68	126.75	128.11	131.47	137.67	139.67	139.50	133.88	128.58	157.49	159.54	162.20	163.67	164.35
T(11)	116.70	118.92	122.12	123.72	126.95	131.81	135.16	133.94	129.46	124.16	152.67	155.70	159.07	160.45	161.32
TEIL	101.85	101.96	102.13	102.16	101.68	100.62	101.47	101.23	102.85	103.12	129.40	131.16	133.67	135.81	137.60
TEI	102.93	103.17	103.41	103.65	103.20	101.25	102.58	101.93	104.20	104.47	132.47	136.68	140.74	143.11	145.68
TEO	114.91	114.22	113.71	113.71	117.29	103.24	110.63	104.30	116.61	116.44	149.19	152.70	152.70	154.28	156.30
TEOL	115.41	115.40	115.93	115.83	115.42	113.50	114.69	113.78	116.47	116.88	148.09	150.11	151.80	153.41	155.37
TRATIO	0.08	0.09	0.09	0.11	0.11	0.05	0.08	0.06	0.10	0.10	0.16	0.29	0.39	0.41	0.45
QL	34.17	34.57	35.42	36.48	38.38	59.96	55.07	60.67	39.81	36.03	68.39	68.07	67.78	67.93	67.53
Q	1304.80	1304.40	1348.13	1336.43	1332.85	1320.19	1311.70	1312.24	1335.88	1337.96	3958.66	3988.40	3996.34	4029.84	3953.68
HC	30.51	29.49	32.85	30.54	25.99	10.62	12.79	10.42	27.47	32.37	60.79	67.20	74.67	81.03	83.67
AGRPM	153.38	116.09	78.80	59.81	41.70	23.46	5.73	23.43	40.71	77.45	332.92	414.54	483.78	574.67	697.03
RER	238.4	181.0	124.6	94.7	65.1	34.2	8.7	34.7	65.8	126.6	1336.2	1791.9	2233.5	2783.5	3565.2
WLBH	207.3	207.3	206.3	206.3	204.4	212.6	206.4	216.9	206.2	205.2	412.0	407.5	411.0	402.7	398.4
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.07	0.10	0.16

TABLE VIII (Continued)

DATE TIME	07/05 1325	07/05 1355	07/05 1420	07/05 1455	07/07 1045	07/07 1120	07/07 1210	07/07 1245	07/07 1320	07/07 1355	07/07 1425	07/07 1455	07/07 1530	07/07 1605	07/07 1640
T(1)	174.84	175.75	177.45	178.96	127.39	128.21	131.16	134.96	140.14	153.18	162.33	165.42	163.44	157.32	157.15
T(2)	175.24	176.18	177.52	179.29	128.61	128.95	132.35	135.84	140.99	155.97	163.67	165.89	163.84	158.30	157.82
T(3)	175.44	176.25	177.49	179.22	129.46	129.29	133.30	135.98	142.61	157.86	164.01	165.52	163.61	158.53	158.19
T(4)	175.24	175.98	177.15	178.82	130.92	130.52	134.38	136.76	144.74	158.23	163.10	164.08	162.83	158.16	157.69
T(5)	173.57	174.47	175.64	177.18	132.32	131.43	134.52	136.89	146.70	157.32	160.38	161.05	160.25	156.68	156.34
T(6)	171.09	172.06	173.27	174.94	131.91	130.69	134.05	137.26	147.38	154.96	157.15	157.62	156.98	154.69	154.49
T(7)	169.61	170.62	171.93	173.60	129.46	129.09	133.57	136.45	146.53	151.32	152.84	153.31	153.28	151.80	151.46
T(8)	167.80	168.74	169.92	171.63	127.49	128.38	132.35	135.16	143.93	146.67	147.85	148.25	148.69	147.85	147.61
T(9)	166.70	167.57	168.78	170.49	126.61	127.46	130.79	133.50	140.11	141.60	142.54	143.02	143.66	143.42	143.32
T(10)	165.52	166.39	167.77	169.45	123.62	124.67	127.43	129.97	134.42	135.37	136.38	137.03	138.04	138.62	138.62
T(11)	162.73	163.74	165.19	166.90	118.57	119.94	122.94	125.35	128.75	129.84	130.96	165.45	133.40	134.72	134.72
TEIL	139.26	139.77	139.80	140.11	102.37	101.61	101.58	101.85	102.09	101.96	102.47	102.92	103.22	102.95	102.81
TEI	148.72	150.71	153.34	155.59	103.17	102.48	102.62	103.06	102.93	102.76	102.93	103.51	104.06	103.61	103.30
TEO	159.47	161.42	163.90	166.19	113.03	114.05	113.37	109.26	108.58	104.47	104.37	105.16	106.53	113.03	113.71
TEOL	158.19	160.21	162.57	164.88	114.09	113.15	112.90	113.47	113.54	112.99	113.34	113.70	114.53	114.25	114.12
TRATIO	0.50	0.53	0.59	0.63	0.07	0.08	0.09	0.10	0.07	0.07	0.04	0.06	0.07	0.06	0.04
QL	68.16	68.79	69.80	71.25	33.94	33.66	36.34	38.01	43.81	54.14	58.04	58.83	57.82	54.08	53.71
Q	3982.44	3933.14	3960.82	3996.96	1350.30	1339.94	1352.39	1350.72	1329.79	1321.14	1327.88	1325.41	1326.42	1330.16	1330.53
HC	100.86	106.23	115.21	121.63	29.36	28.66	25.46	25.29	17.65	12.03	11.54	11.67	11.72	13.40	13.68
AGRPM	812.63	922.61	1014.26	1087.58	133.17	97.23	59.92	47.81	37.70	30.27	23.06	16.28	9.21	5.24	4.85
RER	4463.9	5320.0	6200.0	7015.2	201.8	143.1	87.9	71.4	56.3	44.5	34.3	24.6	14.2	8.0	7.4
WLBH	390.3	389.8	382.2	378.1	247.8	247.9	252.3	245.1	243.7	249.4	253.7	255.1	243.5	245.0	245.0
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.23	0.31	0.37	0.43	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE VIII (Continued)

DATE TIME	07/07 1715	07/05 1355	07/05 1420	07/05 1455	07/07 1045	07/07 1120	07/07 1210	07/07 1245	07/07 1320	07/07 1355	07/07 1425	07/07 1455	07/07 1530	07/07 1605	07/07 1640
T(1)	128.58	175.75	177.45	178.96	127.39	128.21	131.16	134.96	140.14	153.18	162.33	165.42	163.44	157.32	157.15
T(2)	128.07	176.18	177.52	179.29	128.61	128.95	132.35	135.84	140.99	155.97	163.67	165.89	163.84	158.30	157.82
T(3)	130.14	176.25	177.49	179.22	129.46	129.29	133.30	135.98	142.61	157.86	164.01	165.52	163.61	158.53	158.19
T(4)	131.67	175.98	177.15	178.82	130.92	130.52	134.38	136.76	144.74	158.23	163.10	164.08	162.83	158.16	157.69
T(5)	132.72	174.47	175.64	177.18	132.32	131.43	134.52	136.89	146.70	157.32	160.38	161.05	160.25	156.68	156.34
T(6)	133.13	172.06	173.27	174.94	131.91	130.69	134.05	137.26	147.38	154.96	157.15	157.62	156.98	154.69	154.49
T(7)	132.01	170.62	171.93	173.60	129.46	129.09	133.57	136.45	146.53	151.32	152.84	153.31	153.28	151.80	151.46
T(8)	130.24	168.74	169.92	171.63	127.49	128.38	132.35	135.16	143.93	146.67	147.85	148.25	148.69	147.85	147.61
T(9)	127.05	167.57	168.78	170.49	126.61	127.46	130.79	133.50	140.11	141.60	142.54	143.02	143.66	143.42	143.32
T(10)	121.34	166.39	167.77	169.45	123.62	124.67	127.43	129.97	134.42	135.37	136.38	137.03	138.04	138.62	138.62
T(11)	116.15	163.74	165.19	166.90	118.57	119.94	122.94	125.35	128.75	129.84	130.96	165.45	133.40	134.72	134.72
TEIL	104.32	139.77	139.80	140.11	102.37	101.61	101.58	101.85	102.09	101.96	102.47	102.92	103.22	102.95	102.81
TEI	105.33	150.71	153.34	155.59	103.17	102.48	102.62	103.06	102.93	102.76	102.93	103.51	104.06	103.61	103.30
TEO	116.65	161.42	163.90	166.19	113.03	114.05	113.37	109.26	108.58	104.47	104.37	105.16	106.53	113.03	113.71
TEOL	116.91	160.21	162.57	164.88	114.09	113.15	112.90	113.47	113.54	112.99	113.34	113.70	114.53	114.25	114.12
TRATIO	0.08	0.53	0.59	0.63	0.07	0.08	0.09	0.10	0.07	0.07	0.04	0.06	0.07	0.06	0.04
QL	34.45	68.79	69.80	71.25	33.94	33.66	36.34	38.01	43.81	54.14	58.04	58.83	57.82	54.08	53.71
Q	1366.68	3933.14	3960.82	3996.96	1350.30	1339.94	1352.39	1350.72	1329.79	1321.14	1327.88	1325.41	1326.42	1330.16	1330.53
HC	34.24	106.23	115.21	121.63	29.36	28.66	25.46	25.29	17.65	12.03	11.54	11.67	11.72	13.40	13.68
AGRPM	249.20	922.61	1014.26	1087.58	133.17	97.23	59.92	47.81	37.70	30.27	23.06	16.28	9.21	5.24	4.85
RER	412.0	5320.0	6200.0	7015.2	201.8	143.1	87.9	71.4	56.3	44.5	34.3	24.6	14.2	8.0	7.4
WLBH	240.5	389.8	382.2	378.1	247.8	247.9	252.3	245.1	243.7	249.4	253.7	255.1	243.5	245.0	245.0
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.03	0.31	0.37	0.43	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE IX

DATA FOR HEAT TRANSFER TESTS WITH ETHYLENE GLYCOL AND THE 4.000 INCH DIAMETER BLADE

DATE TIME	07-09 1250	07-09 1305	07-09 1332	07-09 1346	07-09 1409	07-09 1420	07-09 1500	07-09 1517	07-09 1543	07-09 1622	07-12 1015	07-12 1035	07-12 1047	07-12 1124	07-12 1135
T(1)	92.54	92.54	98.08	96.74	94.91	91.26	90.58	90.16	89.96	88.65	99.76	96.70	93.47	91.95	91.20
T(2)	93.26	93.23	99.42	97.32	95.74	91.61	90.89	90.47	90.27	101.13	101.06	96.74	93.81	92.23	91.40
T(3)	93.23	93.16	100.45	97.53	95.64	91.57	90.95	90.51	88.58	101.89	102.50	96.43	93.67	92.19	91.37
T(4)	93.30	93.12	100.72	97.35	95.57	91.64	90.95	90.47	90.30	101.96	102.98	96.25	93.64	92.09	91.30
T(5)	92.95	92.81	101.41	97.39	95.39	91.47	90.78	90.27	90.16	102.33	102.30	95.88	93.26	92.23	91.09
T(6)	92.95	92.99	100.96	97.32	95.50	91.51	90.78	90.23	90.20	102.30	101.27	95.84	93.23	91.78	90.99
T(7)	92.85	92.88	100.17	96.77	95.15	91.44	90.71	90.20	90.13	101.82	100.03	95.60	93.12	91.64	90.89
T(8)	92.81	92.78	99.24	96.84	95.15	91.33	90.64	90.13	90.09	101.23	98.59	95.53	92.81	91.47	90.82
T(9)	92.88	92.81	96.32	96.70	95.36	91.40	90.71	90.09	90.16	98.63	97.08	95.67	92.81	91.44	90.78
T(10)	92.54	92.44	94.50	94.26	94.19	91.16	90.51	89.92	90.06	96.29	96.98	94.67	92.47	91.23	90.61
T(11)	91.40	91.37	93.95	92.81	92.19	90.33	89.78	89.37	89.58	95.46	96.67	92.61	91.44	90.40	89.96
TEIL	86.44	86.44	86.30	86.33	86.30	86.54	86.58	86.64	87.16	86.99	84.85	86.09	86.68	86.89	87.13
TEI	87.17	87.24	87.24	87.13	87.07	87.38	87.48	87.51	88.20	87.89	86.24	86.96	87.51	87.76	88.17
TEO	88.38	88.45	88.31	88.31	88.27	88.58	88.62	88.69	89.45	89.34	87.69	88.51	89.03	89.24	89.62
TEOL	88.38	88.45	88.31	88.31	88.27	88.58	88.62	88.69	89.45	89.34	87.69	88.51	89.03	89.24	89.62
TRATIO	0.38	0.40	0.47	0.41	0.39	0.41	0.44	0.43	0.46	0.38	0.49	0.36	0.35	0.37	0.42
QL	10.74	10.65	14.89	12.99	11.99	9.85	9.48	9.22	9.13	15.60	16.20	12.37	10.93	10.09	9.66
Q	1868.34	1869.58	1847.77	1837.35	1867.09	1882.82	1889.28	1913.69	1899.21	1948.11	1948.39	1969.38	1950.71	1971.66	1961.43
HC	187.06	195.63	73.00	100.54	126.79	286.46	368.19	471.28	797.23	75.90	65.36	126.02	203.78	295.85	483.97
AGRPM	243.86	243.62	68.18	113.51	155.67	345.30	473.72	604.58	769.43	69.88	29.24	121.94	248.53	429.63	641.96
RER	10905.6	10911.0	3047.8	5070.4	6946.3	15510.3	21305.8	27224.0	35190.4	3184.0	1286.2	5454.7	11243.3	19527.1	29421.0
WLBH	2574.8	2565.8	2564.4	2570.4	2566.0	2543.5	2598.8	2570.1	2604.1	2117.8	2246.0	2368.0	2249.5	2118.9	2272.1
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE IX (Continued)

DATE	07-12	07-12	07-12	07-12	07-12	07-12	07-14	07-14	07-14	07-14	07-14	07-14	07-14	07-14	07-14
TIME	1145	1220	1235	1315	1345	1640	0855	0915	0937	1047	1226	1305	1342	1355	1415
T(1)	91.13	96.67	92.23	131.77	133.88	122.05	116.19	110.45	132.08	128.34	120.07	118.23	106.31	132.32	131.67
T(2)	91.23	97.66	92.64	135.03	132.25	123.17	119.90	113.87	131.87	128.68	121.06	119.53	140.52	131.98	133.33
T(3)	91.23	97.59	92.64	138.62	136.28	125.01	120.35	113.25	131.47	128.55	122.42	120.31	141.80	131.67	133.77
T(4)	91.16	97.42	92.61	139.20	134.86	123.34	119.36	110.00	124.77	125.25	120.72	118.92	141.90	131.16	133.03
T(5)	90.92	97.01	92.40	137.13	135.98	122.53	113.18	111.88	117.28	125.22	119.39	118.20	139.97	132.11	132.99
T(6)	90.82	97.22	92.37	167.33	138.45	123.28	119.02	116.22	136.05	129.23	119.26	117.89	143.15	132.18	133.33
T(7)	90.75	96.91	92.30	131.23	135.81	124.74	115.95	114.17	135.81	129.02	118.92	117.45	133.37	132.45	132.89
T(8)	90.61	96.94	92.16	127.83	132.93	125.52	115.74	113.25	129.09	128.82	118.54	116.19	128.41	131.74	132.11
T(9)	90.58	96.98	92.13	124.57	128.34	126.51	115.64	112.94	125.73	128.72	118.68	118.00	125.05	126.85	127.29
T(10)	90.44	96.05	91.95	124.57	123.14	124.77	113.52	110.69	122.39	128.58	117.21	116.60	124.19	121.20	122.25
T(11)	89.82	93.95	91.16	123.82	120.96	120.45	109.39	108.81	128.31	128.48	113.80	112.98	124.40	117.89	120.55
TEIL	87.30	87.33	87.58	97.08	100.55	100.99	97.59	97.94	98.39	96.19	98.04	98.08	98.52	99.21	99.62
TEI	88.38	88.10	88.45	99.43	101.83	104.06	101.97	102.38	104.09	101.04	99.46	99.32	100.18	100.32	100.83
TEO	89.79	89.65	89.89	103.37	105.53	106.42	98.12	97.74	91.41	102.38	103.65	102.62	102.55	106.87	103.68
TEOL	89.79	89.65	89.89	103.37	105.53	106.42	98.12	97.74	91.41	102.38	103.65	102.62	102.55	106.87	103.68
TRATIO	0.43	0.33	0.37	0.37	0.26	0.56	8.32	0.00	0.00	0.78	0.25	0.27	0.41	0.14	0.30
QL	9.59	13.02	10.37	39.76	36.67	28.83	26.24	20.38	29.78	30.10	27.12	25.95	41.72	34.10	35.39
Q	1948.81	2010.43	1994.86	4854.54	4842.27	5437.66	5195.72	5126.25	4811.11	4875.38	4979.13	4767.73	4697.20	4745.83	4770.34
HC	573.50	128.44	330.20	69.59	80.51	162.55	161.06	231.16	99.92	108.47	144.19	144.47	62.15	90.78	81.58
AGRPM	779.07	145.91	434.60	29.21	68.30	-150.74	263.11	428.77	642.47	775.74	148.06	151.06	29.21	73.03	68.06
RER	35844.2	6686.8	20033.7	1735.2	4235.7	9595.8	14912.2	24258.1	33968.8	46044.6	8827.9	8885.2	1726.8	4555.2	4098.8
WLBH	2222.9	2663.6	2211.7	2340.1	2339.5	2362.6	2056.9	2025.0	1970.0	2021.6	1638.3	1864.7	1899.3	1797.0	1773.7
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE IX (Continued)

DATE	07-14	07-14	07-14	07-14	07-14	07-15	07-15	07-15	07-15	07-15	07-15	07-15	07-14	07-14	07-14
TIME	1453	1503	1523	1545	1600	0845	0910	0950	1020	1047	1103	1129	1342	1355	1415
T(1)	118.78	112.94	110.28	108.23	107.30	136.89	132.15	122.32	114.79	111.13	108.57	108.98	106.31	132.32	131.67
T(2)	120.07	113.93	110.65	108.57	107.99	137.16	133.67	123.14	115.10	110.52	109.29	109.11	140.52	131.98	133.33
T(3)	119.97	113.11	110.04	107.81	107.44	139.64	133.13	122.25	114.51	110.28	108.23	108.81	141.80	131.67	133.77
T(4)	119.60	113.42	110.28	107.64	107.61	143.76	131.70	120.38	114.00	109.53	108.57	107.92	141.90	131.16	133.03
T(5)	119.22	113.08	110.11	107.30	107.37	148.09	130.45	118.85	114.11	108.94	107.10	107.47	139.97	132.11	132.99
T(6)	119.43	113.42	109.42	107.13	106.82	147.58	129.84	118.13	112.81	108.81	106.68	106.72	143.15	132.18	133.33
T(7)	117.14	112.81	109.25	107.13	106.96	144.91	129.26	118.06	111.41	108.09	107.23	106.45	133.37	132.45	132.89
T(8)	118.92	111.99	109.46	107.06	106.72	142.17	128.27	118.10	111.99	107.85	106.55	106.10	128.41	131.74	132.11
T(9)	119.67	113.56	109.25	107.27	107.03	134.21	129.26	117.72	113.63	108.33	106.86	106.34	125.05	126.85	127.29
T(10)	118.20	112.06	109.35	107.16	106.89	129.33	126.98	116.49	110.89	107.37	106.58	105.79	124.19	121.20	122.25
T(11)	114.62	109.90	107.95	105.76	106.03	127.56	121.51	114.14	108.94	106.17	106.48	105.01	124.40	117.89	120.55
TEIL	99.38	98.73	99.11	98.66	99.86	94.26	97.80	97.84	97.80	97.49	98.59	98.52	98.52	99.21	99.62
TEI	99.87	99.67	100.11	100.22	100.87	97.12	98.64	99.39	98.91	99.32	99.46	100.90	100.18	100.32	100.83
TEO	106.59	102.82	103.10	106.73	103.75	102.48	104.09	105.26	103.82	103.10	104.68	104.57	102.55	106.87	103.68
TEOL	106.59	102.82	103.10	106.73	103.75	102.48	104.09	105.26	103.82	103.10	104.68	104.57	102.55	106.87	103.68
TRATIO	0.07	0.23	0.25	0.19	0.26	0.35	0.13	0.21	0.18	0.33	0.14	0.39	0.41	0.14	0.30
QL	26.39	22.48	20.54	18.95	18.93	43.08	34.48	26.90	22.84	20.09	19.51	19.12	41.72	34.10	35.39
Q	4805.14	4795.27	4868.63	4853.48	4902.84	4800.55	4658.37	4743.36	4744.09	4778.65	4885.03	5020.07	4697.20	4745.83	4770.34
HC	163.52	215.13	309.09	810.37	531.82	54.92	83.51	149.38	204.96	330.47	502.09	584.94	62.15	90.78	81.58
AGRPM	150.88	270.16	430.78	643.07	774.71	34.03	72.93	155.17	271.95	433.47	646.48	773.01	29.21	73.03	68.06
RER	9351.6	15968.9	25628.8	40017.5	46706.4	1967.6	4347.0	9431.4	16186.2	25646.6	39033.4	47084.7	1726.8	4555.2	4098.8
WLBH	1804.6	1826.6	1737.0	1708.4	1687.9	800.7	783.4	1044.0	1309.9	1324.9	1294.1	1220.5	1899.3	1797.0	1773.7
TORQUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE X

DATA FOR AGITATOR POWER REQUIREMENT TESTS WITH THE 3.500 INCH DIAMETER BLADE

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
03/29/1412	1	4.75	79.91	0.41	2.18	80.77	2499.62	2406.66	0.00442	11.25	128.08	15.01	11.10
03/29/1414	1	8.75	79.98	0.55	4.17	81.01	2492.03	2381.37	0.01397	35.57	211.51	25.05	7.79
03/29/1416	1	5.75	80.25	0.44	2.68	81.01	2461.94	2381.37	0.00615	15.67	144.83	17.16	10.69
03/29/1419	1	9.75	80.29	0.60	4.65	81.22	2458.20	2359.94	0.01769	45.02	239.80	28.66	6.77
03/29/1420	1	6.75	80.60	0.49	3.17	81.36	2424.92	2345.78	0.00862	21.93	171.51	20.62	9.01
03/29/1421	1	10.75	80.74	0.65	5.13	81.53	2410.30	2328.22	0.02204	56.11	270.89	32.81	5.85
03/29/1423	1	7.75	80.94	0.52	3.67	81.67	2388.56	2314.29	0.01108	28.20	190.44	23.20	8.47
03/29/1425	1	11.75	81.12	0.69	5.62	81.84	2370.62	2297.01	0.02639	67.17	295.99	36.33	5.37
03/29/1426	1	5.25	81.19	0.43	2.42	81.86	2363.49	2295.29	0.00535	13.61	139.14	17.09	10.48
03/29/1427	1	12.25	81.32	0.70	5.88	82.15	2349.31	2266.30	0.02915	74.19	312.44	38.86	5.05
03/29/1429	1	6.25	81.50	0.47	2.91	82.15	2331.72	2266.30	0.00755	19.23	163.43	20.33	9.14
03/29/1431	1	12.75	81.88	0.70	6.15	84.47	2293.57	2052.36	0.03269	83.22	335.29	45.98	4.59
03/29/1436	1	7.25	81.46	0.51	3.41	81.15	2335.23	2367.06	0.00992	25.25	183.22	21.83	8.51
03/29/1439	1	13.25	81.46	0.70	6.41	81.55	2335.23	2326.48	0.03337	84.96	328.07	39.76	4.99
03/29/1440	1	8.25	81.50	0.55	3.91	81.74	2331.72	2307.36	0.01288	32.78	207.90	25.41	7.56
03/29/1441	1	13.75	81.60	0.70	6.68	82.22	2321.24	2259.54	0.03686	93.83	347.90	43.40	4.62
03/29/1442	1	9.25	81.88	0.60	4.38	82.40	2293.57	2242.74	0.01678	42.73	241.56	30.36	6.29
03/29/1445	1	14.25	82.05	0.70	6.95	83.00	2276.48	2185.12	0.04083	103.94	370.61	47.78	4.24
03/29/1446	1	10.25	82.43	0.65	4.86	83.09	2239.40	2177.04	0.02095	53.33	271.63	35.15	5.52
03/29/1448	1	14.75	82.67	0.70	7.21	83.57	2216.18	2132.40	0.04541	115.59	396.96	52.43	3.84
03/29/1449	1	11.25	82.88	0.70	5.35	83.74	2196.51	2116.73	0.02612	66.48	307.85	40.96	4.73
03/29/1450	1	15.25	83.19	0.70	7.48	83.92	2167.38	2101.19	0.04799	122.16	404.57	54.22	3.83
03/29/1451	1	12.25	83.71	0.70	5.88	84.57	2119.85	2043.36	0.03208	81.67	343.93	47.37	4.17
03/29/1454	1	15.75	84.02	0.70	7.75	84.75	2091.93	2028.46	0.05399	137.43	439.52	60.98	3.36
03/29/1455	1	16.75	84.40	0.70	8.28	85.25	2058.39	1985.98	0.06143	156.38	467.96	66.29	3.17
03/29/1456	1	17.75	84.61	0.70	8.81	85.61	2040.37	1955.87	0.07039	179.19	503.80	72.45	2.91

TABLE X (Continued)

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
03/29/1457	1	18.75	84.99	0.70	9.34	85.75	2007.82	1944.55	0.08371	213.10	565.01	81.72	2.46
03/29/1459	1	19.75	85.30	0.70	9.88	85.99	1981.64	1924.92	0.08075	205.57	515.65	75.33	3.12
03/29/1460	1	20.75	85.78	0.70	10.41	86.47	1941.73	1886.36	0.09759	248.43	591.29	88.12	2.50
03/29/1501	1	21.75	86.16	0.70	10.94	86.89	1911.04	1854.05	0.10756	273.82	619.99	93.99	2.39
03/29/1502	2	14.00	88.54	0.70	11.98	91.64	1731.24	1526.23	0.12344	314.23	649.65	119.28	2.39
03/29/1503	2	15.75	87.23	0.70	13.55	87.83	1827.63	1782.46	0.17638	449.00	821.06	129.39	1.69
03/29/1505	2	17.75	88.13	0.70	15.33	88.37	1761.00	1743.57	0.20476	521.25	842.03	135.61	1.82
03/29/1506	2	19.75	89.02	0.70	17.12	89.30	1697.27	1678.22	0.24267	617.74	893.71	149.45	1.80
03/29/1507	2	21.75	90.09	0.70	18.91	89.97	1624.86	1632.85	0.30673	780.81	1022.82	175.72	1.52
05/25/1620	1	5.75	63.17	0.28	2.84	62.68	5480.38	5615.83	0.00211	5.36	46.70	2.37	107.89
05/25/1622	1	7.75	63.10	0.32	3.87	62.70	5499.50	5610.93	0.00425	10.81	69.18	3.52	66.93
05/25/1623	1	9.75	63.07	0.35	4.90	62.79	5509.09	5586.49	0.00694	17.66	89.23	4.56	50.95
05/25/1625	1	6.75	63.10	0.30	3.36	62.72	5499.50	5606.03	0.00304	7.73	57.05	2.90	85.41
05/25/1626	1	8.75	63.10	0.33	4.39	62.96	5499.50	5537.96	0.00550	13.99	78.99	4.07	58.19
05/25/1628	1	11.75	63.13	0.39	5.93	62.96	5489.93	5537.96	0.01069	27.20	113.71	5.86	37.93
05/25/1629	1	13.75	63.13	0.43	6.95	63.13	5489.93	5489.93	0.01508	38.38	136.75	7.10	30.77
05/25/1630	1	15.75	63.27	0.47	7.98	63.27	5451.85	5451.85	0.02042	51.98	161.42	8.44	25.34
05/25/1631	1	10.75	63.41	0.37	5.42	63.41	5414.08	5414.08	0.00858	21.85	99.91	5.26	44.92
05/25/1632	1	12.75	63.52	0.41	6.43	63.52	5385.95	5385.95	0.01304	33.20	127.81	6.77	32.61
05/25/1634	1	14.75	63.52	0.46	7.46	63.62	5385.95	5357.99	0.01809	46.06	152.98	8.14	26.39
05/25/1635	1	16.75	63.59	0.49	8.48	63.90	5367.29	5284.25	0.02365	60.21	175.80	9.48	22.73
05/25/1636	1	18.75	63.80	0.54	9.50	64.21	5311.76	5202.69	0.03056	77.79	202.75	11.11	19.15
05/25/1637	1	20.75	63.97	0.58	10.53	64.67	5266.00	5087.45	0.03791	96.51	227.07	12.72	16.92
05/25/1639	1	17.75	64.21	0.52	8.99	64.98	5202.69	5009.41	0.02726	69.40	191.20	10.87	20.38
05/25/1640	1	19.75	64.42	0.57	10.01	65.02	5149.13	5000.82	0.03512	89.41	221.34	12.61	16.92
05/25/1641	1	21.75	64.67	0.61	11.03	65.50	5087.45	4882.40	0.04276	108.84	244.40	14.26	15.31

TABLE X (Continued)

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
05/25/1642	2	11.75	65.05	0.56	10.11	65.89	4992.25	4791.64	0.03449	87.80	215.11	12.78	18.12
05/25/1643	2	12.75	65.33	0.62	10.95	66.27	4924.32	4702.84	0.04325	110.10	249.10	15.08	14.63
05/25/1644	2	13.75	65.68	0.66	11.80	66.56	4840.90	4635.53	0.05150	131.10	275.24	16.90	12.92
05/25/1645	2	15.75	65.89	0.70	13.55	67.28	4791.64	4477.76	0.06983	177.75	325.04	20.65	10.64
05/25/1646	2	17.75	66.44	0.70	15.33	67.76	4663.11	4373.60	0.09070	230.90	372.99	24.25	9.15
05/25/1647	2	19.75	66.83	0.70	17.12	68.63	4577.07	4194.56	0.11654	296.65	429.18	29.08	7.72
05/25/1648	2	21.75	67.76	0.70	18.91	69.54	4373.60	4017.35	0.14639	372.66	488.16	34.52	6.59
05/25/1649	3	15.75	68.81	0.70	18.74	71.07	4159.78	3737.01	0.15253	388.29	513.14	38.97	5.92
05/25/1651	3	17.75	70.20	0.70	21.17	72.63	3893.38	3473.70	0.20686	526.58	616.05	50.29	4.64
05/25/1652	3	19.75	71.31	0.70	23.60	74.71	3694.56	3155.71	0.26702	679.72	713.36	64.01	3.87
05/25/1654	3	21.75	73.50	0.70	26.03	76.86	3336.83	2862.48	0.34783	885.43	842.53	83.24	3.06
05/25/1655	23	11.75	75.82	0.70	25.01	80.98	3000.16	2384.96	0.34963	890.02	881.47	104.26	2.69
05/25/1656	23	12.75	78.66	0.70	27.12	83.19	2641.08	2167.38	0.46073	1172.85	1071.27	139.24	1.98
06/05/1600	1	4.75	72.80	0.78	1.81	73.81	3445.80	3289.12	0.00206	5.24	71.77	6.18	29.25
06/05/1601	1	8.75	72.84	1.13	3.59	73.76	3440.26	3297.01	0.00784	19.96	137.82	11.84	15.74
06/05/1602	1	6.75	73.01	0.96	2.70	73.72	3412.68	3302.29	0.00448	11.42	104.79	8.99	20.48
06/05/1605	1	10.75	73.18	1.19	4.59	73.81	3385.36	3289.12	0.01277	32.51	175.33	15.10	12.45
06/05/1606	1	12.75	73.29	1.19	5.66	74.02	3369.09	3257.75	0.01888	48.06	210.38	18.29	10.65
06/05/1607	1	16.75	73.53	1.19	7.79	74.29	3331.49	3216.48	0.03448	87.76	279.14	24.58	8.33
06/05/1608	1	14.75	73.64	1.19	6.72	74.57	3315.52	3175.82	0.02668	67.93	250.26	22.32	8.95
06/05/1610	1	18.75	73.98	1.19	8.85	74.99	3262.95	3115.95	0.04480	114.05	319.12	29.00	7.25
06/05/1611	1	22.00	74.22	1.19	10.58	75.27	3226.74	3076.78	0.06427	163.60	382.92	35.23	6.02
06/05/1612	1	20.75	74.75	1.19	9.92	76.10	3150.71	2962.70	0.05846	148.82	371.70	35.50	5.99

TABLE XI

DATA FOR AGITATOR POWER REQUIREMENT TESTS WITH THE 3.831 INCH DIAMETER BLADE

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
05/16/1420	1	6.75	65.71	0.65	3.01	63.80	4832.65	5311.76	0.00222	5.65	46.57	2.50	114.79
05/16/1421	1	10.75	32.37	0.42	5.36	63.95	30856.36	5270.55	0.00624	15.88	73.36	4.75	57.50
05/16/1424	1	8.75	65.12	0.39	4.33	64.15	4975.17	5220.69	0.00402	10.23	58.51	3.83	73.04
05/16/1426	1	14.75	64.98	0.50	7.41	64.48	5009.41	5135.84	0.01259	32.04	107.05	7.12	37.34
05/16/1427	1	12.75	32.37	0.45	6.39	64.60	30856.36	5104.99	0.00895	22.78	88.26	5.90	47.38
05/16/1429	1	18.75	65.05	0.60	9.44	64.91	4992.25	5026.63	0.02264	57.64	151.21	10.27	23.84
05/16/1430	1	16.75	65.29	0.54	8.44	65.12	4932.75	4975.17	0.01645	41.88	122.88	8.43	32.28
05/16/1432	1	22.15	65.61	0.64	11.21	65.50	4857.45	4882.40	0.02978	75.82	167.47	11.70	23.09
05/16/1433	1	20.75	65.68	0.62	10.49	65.85	4840.90	4799.81	0.02623	66.76	157.63	11.20	24.39
05/16/1435	2	12.75	32.37	0.63	10.93	66.37	30856.36	4678.96	0.02836	72.18	163.51	11.92	23.63
05/16/1437	2	16.75	66.44	0.77	14.37	66.84	4663.11	4573.20	0.05067	128.98	222.27	16.57	16.82
05/16/1438	2	14.75	32.37	0.71	12.64	67.21	30856.36	4492.87	0.04010	102.08	200.08	15.18	18.25
05/16/1440	2	20.75	67.42	0.91	17.81	68.10	4447.71	4304.53	0.08032	204.46	284.44	22.51	12.73
05/16/1441	2	18.75	32.37	0.87	16.06	68.63	30856.36	4194.56	0.06796	172.99	266.84	21.66	13.05
05/16/1443	3	14.65	32.37	0.94	17.17	69.61	30856.36	4004.09	0.08088	205.88	297.04	25.25	11.27
05/16/1444	3	16.75	32.37	1.06	19.59	70.37	30856.36	3861.50	0.10904	277.58	350.90	30.91	9.22
05/16/1445	3	18.75	70.23	1.18	21.91	71.76	3886.98	3617.19	0.14446	367.73	415.78	39.07	7.35
05/16/1446	3	20.75	32.37	1.18	24.34	73.18	30856.36	3385.36	0.17964	457.31	465.45	46.69	6.52
05/16/1449	23	11.75	74.19	1.18	24.53	75.92	3231.88	2986.05	0.19968	508.32	513.29	58.28	5.41
05/16/1450	23	13.75	32.37	1.18	28.75	78.31	30856.36	2682.04	0.28336	721.34	621.53	78.45	4.33
05/16/1451	23	15.75	32.37	1.18	32.97	80.94	30856.36	2388.56	0.38444	978.64	735.36	104.05	3.55
05/16/1452	23	17.75	32.37	1.18	37.18	83.71	30856.36	2119.85	0.52904	1346.72	897.16	142.79	2.70
05/16/1645	1	7.75	71.97	0.39	3.80	66.48	3582.13	4655.21	0.00366	9.32	60.84	4.46	59.24
05/16/1647	1	9.75	70.89	0.43	4.82	66.88	3767.69	4565.48	0.00605	15.41	79.21	5.91	44.37
05/16/1648	1	11.75	70.34	0.48	5.84	67.28	3867.86	4477.76	0.00910	23.17	98.32	7.48	34.91
05/16/1649	1	13.75	32.37	0.52	6.86	67.52	30856.36	4425.32	0.01282	32.63	117.88	9.08	28.53

TABLE XI (Continued)

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
05/16/1651	1	15.75	32.37	0.57	7.88	67.80	30856.36	4366.27	0.01716	43.68	137.37	10.72	24.14
05/16/1652	1	17.75	69.57	0.61	8.90	68.20	4010.72	4282.99	0.02188	55.70	155.03	12.33	21.42
05/16/1653	1	19.75	32.37	0.65	9.92	68.63	30856.36	4194.56	0.02746	69.89	174.53	14.17	18.84
05/16/1655	1	21.75	32.37	0.72	10.92	69.19	30856.36	4084.46	0.03538	90.06	204.38	17.03	15.13
05/16/1658	23	9.75	70.20	1.08	20.41	70.41	3893.38	3855.17	0.11587	294.97	357.93	31.58	9.23
05/16/1660	23	11.75	32.37	1.18	24.53	71.87	30856.36	3599.61	0.17127	435.98	440.24	41.57	7.34
05/16/1701	23	13.75	32.37	1.18	28.75	73.53	30856.36	3331.49	0.24612	626.52	539.84	55.02	5.72
05/16/1702	23	15.75	74.02	1.18	32.97	76.10	3257.75	2962.70	0.33698	857.81	644.57	73.75	4.61
05/16/1703	23	17.75	32.37	1.18	37.18	80.25	30856.36	2461.94	0.50107	1275.52	849.74	116.70	3.00

TABLE XII

DATA FOR AGITATOR POWER REQUIREMENT TESTS WITH THE 4.000 INCH DIAMETER BLADE

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
02/15/1600	1	4.75	79.35	0.38	2.21	79.92	2561.36	2497.72	0.00191	4.86	54.43	7.37	43.51
02/15/1610	1	6.75	80.46	0.41	3.25	81.13	2439.65	2368.84	0.00390	9.93	75.79	11.79	27.72
02/15/1615	1	8.75	81.64	0.50	4.22	82.17	2317.76	2264.61	0.00663	16.87	98.95	16.09	21.17
02/15/1620	1	10.75	82.19	0.57	5.21	82.64	2262.91	2219.48	0.00987	25.11	119.41	19.80	17.94
02/15/1623	1	12.75	83.09	0.66	6.18	83.17	2177.04	2168.99	0.01405	35.76	143.26	24.30	14.80
02/15/1626	1	14.75	83.74	0.77	7.15	83.73	2116.73	2118.29	0.01924	48.99	169.77	29.48	12.19
02/15/1630	1	16.75	84.37	0.84	8.14	84.23	2061.41	2073.56	0.02449	62.35	189.81	33.66	11.10
02/15/1632	1	18.75	84.78	0.94	9.10	84.78	2025.50	2025.50	0.03110	79.16	215.37	39.08	9.65
02/15/1635	1	20.75	85.64	1.03	10.07	85.38	1953.03	1974.44	0.03844	97.85	240.63	44.78	8.56
02/15/1640	1	22.25	86.44	1.07	10.84	86.23	1889.09	1905.53	0.04428	112.71	257.64	49.65	8.03
02/15/2010	1	5.75	78.83	0.34	2.78	79.04	2620.88	2596.88	0.00257	6.54	58.26	8.28	40.13
02/15/2013	1	7.75	79.08	0.46	3.73	79.58	2592.90	2536.06	0.00525	13.37	88.80	12.91	23.18
02/15/2016	1	9.75	79.70	0.50	4.75	79.99	2522.57	2490.14	0.00759	19.33	100.85	14.93	22.88
02/15/2019	1	11.75	79.91	0.58	5.73	80.22	2499.62	2465.68	0.01111	28.29	122.28	18.28	18.79
02/15/2024	1	15.75	81.29	0.76	7.69	81.19	2352.85	2363.49	0.02039	51.89	167.15	26.05	13.50
02/15/2027	1	17.75	81.98	0.85	8.66	81.67	2283.30	2314.29	0.02628	66.91	191.30	30.44	11.62
02/15/2029	1	19.75	82.36	0.92	9.65	82.22	2246.09	2259.54	0.03242	82.52	211.82	34.51	10.56
02/15/2031	1	21.75	83.19	1.01	10.63	82.72	2167.38	2211.24	0.03947	100.47	234.12	38.97	9.52
02/15/2034	2	14.75	83.71	1.07	12.28	83.36	2119.85	2151.40	0.04887	124.42	250.92	42.91	9.58
02/15/2036	2	16.75	84.37	1.07	14.07	83.81	2061.41	2110.49	0.06449	164.17	289.02	50.37	8.28
02/15/2039	2	18.75	84.78	1.07	15.86	84.33	2025.50	2064.44	0.07286	185.48	289.73	51.60	9.29
02/15/2041	2	20.75	85.64	1.07	17.65	84.87	1953.03	2018.11	0.10087	256.79	360.47	65.65	6.68
02/15/2044	23	8.75	86.82	1.07	18.32	85.78	1859.39	1941.73	0.10721	272.90	369.10	69.83	6.61
02/15/2048	23	10.75	89.20	1.07	22.53	87.01	1685.33	1844.75	0.16988	432.45	475.41	94.60	4.91
02/15/2051	23	12.75	90.64	1.07	26.75	88.04	1588.93	1767.29	0.23145	589.19	545.60	113.25	4.43
02/15/2054	23	14.75	93.71	1.07	30.97	89.61	1405.69	1657.10	0.31346	797.94	638.28	141.16	3.75

TABLE XII (Continued)

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
02/15/2059	23	16.75	96.15	1.07	35.18	92.85	1277.56	1454.48	0.41316	1051.74	740.46	186.19	3.17
02/15/2122	23	16.75	108.81	1.07	35.18	107.37	800.70	842.42	0.52017	1324.14	932.23	401.08	2.02
02/20/1022	1	5.75	72.32	0.23	2.89	72.30	3524.57	3527.43	0.00136	3.45	29.62	3.11	160.72
02/20/1029	1	4.75	72.32	0.22	2.37	72.40	3524.57	3510.35	0.00099	2.52	26.34	2.78	166.57
02/20/1032	1	5.25	72.35	0.23	2.63	72.46	3518.88	3501.85	0.00120	3.06	28.85	3.05	153.95
02/20/1036	1	6.25	72.49	0.26	3.13	72.47	3496.20	3499.03	0.00178	4.53	35.84	3.79	118.95
02/20/1042	1	6.75	72.66	0.27	3.38	72.68	3468.10	3465.30	0.00213	5.42	39.67	4.24	104.91
02/20/1050	1	7.30	72.77	0.28	3.66	72.68	3451.36	3465.30	0.00248	6.32	42.75	4.57	97.84
02/20/1054	1	7.75	72.80	0.30	3.89	72.87	3445.80	3434.72	0.00292	7.45	47.46	5.12	84.21
02/20/1056	1	9.25	72.94	0.34	4.64	73.05	3423.68	3407.19	0.00432	10.99	58.65	6.37	65.88
02/20/1059	1	8.25	72.98	0.30	4.15	73.03	3418.17	3409.93	0.00320	8.14	48.60	5.28	85.71
02/20/1102	1	9.75	73.08	0.36	4.90	73.10	3401.72	3398.99	0.00480	12.23	61.86	6.74	62.45
02/20/1105	1	8.75	73.15	0.32	4.40	73.17	3390.80	3388.08	0.00364	9.28	52.23	5.71	78.76
02/20/1108	1	11.25	73.29	0.40	5.65	73.32	3369.09	3363.69	0.00662	16.86	73.91	8.13	50.49
02/20/1110	1	10.25	73.39	0.36	5.16	73.50	3352.92	3336.83	0.00518	13.19	63.37	7.03	62.69
02/20/1113	1	12.25	73.53	0.43	6.16	73.53	3331.49	3331.49	0.00785	19.98	80.38	8.93	46.53
02/20/1115	1	12.25	73.57	0.43	6.15	73.67	3326.16	3310.22	0.00789	20.09	80.86	9.04	45.97
02/20/1118	1	13.25	73.81	0.46	6.66	73.81	3289.12	3289.12	0.00938	23.88	88.86	10.00	41.17
02/20/1120	1	11.75	73.91	0.41	5.91	73.96	3273.39	3265.56	0.00710	18.06	75.73	8.58	50.31
02/20/1122	1	14.75	74.09	0.51	7.41	74.09	3247.37	3247.37	0.01195	30.41	101.71	11.59	34.98
02/20/1124	1	13.75	74.22	0.47	6.91	74.22	3226.74	3226.74	0.01013	25.80	92.48	10.60	39.46
02/20/1126	1	15.25	74.40	0.53	7.65	74.42	3201.16	3198.61	0.01303	33.16	107.35	12.42	32.44
02/20/1128	1	14.25	74.50	0.49	7.16	74.50	3185.92	3185.92	0.01094	27.85	96.32	11.18	37.71
02/20/1130	1	16.75	74.85	0.58	8.40	74.83	3135.76	3138.24	0.01607	40.90	120.63	14.22	28.21
02/20/1131	1	15.75	75.02	0.54	7.91	75.02	3111.02	3111.02	0.01380	35.13	110.06	13.08	31.91
02/20/1133	1	17.25	75.33	0.60	8.65	75.21	3067.08	3084.08	0.01722	43.85	125.61	15.06	26.79

TABLE XII (Continued)

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
02/20/1135	1	18.25	75.58	0.62	9.15	75.53	3033.40	3040.58	0.01919	48.86	132.20	16.07	25.61
02/20/1137	1	16.25	75.92	0.57	8.14	75.66	2986.05	3021.48	0.01520	38.70	117.69	14.40	28.75
02/20/1139	1	17.75	76.06	0.63	8.88	75.92	2967.35	2986.05	0.01874	47.70	133.00	16.46	24.56
02/20/1141	1	19.75	76.41	0.69	9.88	76.20	2921.21	2948.79	0.02354	59.93	150.18	18.82	21.43
02/20/1143	1	18.75	76.69	0.66	9.38	76.58	2884.90	2898.45	0.02124	54.06	142.75	18.20	22.52
02/20/1145	1	20.25	76.96	0.72	10.12	76.82	2849.13	2866.95	0.02537	64.58	158.05	20.36	19.82
02/20/1146	1	19.25	77.28	0.67	9.64	77.07	2809.50	2835.84	0.02224	56.61	145.53	18.95	22.26
02/20/1147	1	21.25	77.55	0.76	10.61	77.47	2774.82	2785.61	0.02852	72.59	169.49	22.47	18.08
02/20/1149	1	22.25	78.00	0.82	11.09	77.79	2719.55	2744.90	0.03224	82.06	183.30	24.65	16.16
02/20/1151	1	20.75	78.42	0.76	10.35	78.18	2669.67	2698.63	0.02755	70.14	167.88	22.96	17.98
02/20/1152	1	21.75	78.73	0.80	10.84	78.52	2632.98	2657.38	0.03090	78.66	179.79	24.97	16.42
03/17/1708	1	4.75	68.50	0.19	2.39	68.46	4222.62	4229.67	0.00075	1.90	19.65	1.72	301.94
03/17/1712	1	9.75	68.46	0.31	4.94	68.50	4229.67	4222.62	0.00391	9.95	49.89	4.39	96.64
03/17/1714	1	6.75	68.50	0.24	3.41	68.50	4222.62	4222.62	0.00173	4.40	31.91	2.81	163.16
03/17/1717	1	11.75	68.53	0.36	5.96	68.50	4215.58	4222.62	0.00586	14.92	61.99	5.45	75.51
03/17/1720	1	7.75	68.63	0.26	3.92	68.63	4194.56	4194.56	0.00236	6.02	38.00	3.36	132.24
03/17/1722	1	12.75	68.67	0.38	6.47	68.88	4187.57	4145.96	0.00707	17.99	68.92	6.17	66.28
03/17/1725	1	8.75	68.98	0.29	4.43	69.05	4125.34	4111.66	0.00308	7.85	43.86	3.96	112.18
03/17/1727	1	5.75	69.02	0.22	2.90	69.07	4118.49	4108.25	0.00125	3.18	27.15	2.45	191.47
03/17/1734	1	13.75	69.16	0.41	6.97	69.33	4091.24	4057.46	0.00833	21.20	75.29	6.89	59.93
03/17/1735	1	5.25	69.19	0.21	2.65	69.36	4084.45	4050.74	0.00099	2.51	23.53	2.16	232.76
03/17/1737	1	14.75	69.36	0.43	7.48	69.64	4050.74	3997.48	0.00980	24.95	82.62	7.67	53.37
03/17/1739	1	6.25	69.47	0.24	3.15	69.68	4030.67	3990.88	0.00152	3.88	30.47	2.83	165.40
03/17/1740	1	15.75	69.50	0.46	7.98	69.71	4024.01	3984.29	0.01142	29.07	90.22	8.40	47.78
03/17/1742	1	7.25	69.64	0.25	3.67	69.80	3997.48	3967.87	0.00205	5.21	35.21	3.29	144.11
03/17/1744	1	16.75	69.68	0.49	8.49	69.89	3990.88	3951.54	0.01312	33.41	97.50	9.15	43.50

TABLE XII (Continued)

DATE	NW	XLA	TW	TF	T	TFAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
03/17/1745	1	8.25	69.68	0.29	4.16	69.99	3990.88	3932.04	0.00291	7.42	44.13	4.16	104.21
03/17/1749	1	9.25	70.23	0.33	4.65	70.34	3886.98	3867.86	0.00413	10.51	55.95	5.36	72.43
03/17/1752	1	17.75	70.30	0.52	8.99	70.51	3874.22	3836.22	0.01497	38.12	105.01	10.15	39.74
03/17/1754	1	10.25	70.55	0.34	5.18	70.58	3829.93	3823.65	0.00478	12.16	58.19	5.64	74.51
03/17/1756	1	18.75	70.62	0.55	9.49	70.68	3817.39	3804.89	0.01718	43.73	114.16	11.12	35.49
03/17/1757	1	11.25	70.89	0.38	5.67	70.89	3767.69	3767.69	0.00623	15.85	69.27	6.82	57.56
03/17/1759	1	19.75	71.07	0.59	9.99	71.07	3737.01	3737.01	0.01939	49.36	122.39	12.14	32.52
03/17/1800	1	12.25	71.10	0.40	6.19	71.10	3730.91	3730.91	0.00714	18.16	72.74	7.23	57.00
03/17/1802	1	20.75	71.31	0.62	10.49	71.38	3694.56	3682.53	0.02180	55.50	131.06	13.19	29.78
03/17/1805	1	13.25	71.45	0.43	6.69	71.55	3670.55	3652.66	0.00853	21.72	80.44	8.16	50.41
03/17/1806	1	21.75	71.73	0.65	10.99	71.73	3623.08	3623.08	0.02421	61.63	138.89	14.21	27.79
03/17/1807	1	14.25	71.87	0.45	7.19	71.87	3599.61	3599.61	0.01005	25.58	88.09	9.07	45.21
03/17/1809	1	22.25	72.11	0.67	11.24	72.11	3558.98	3558.98	0.02560	65.17	143.62	14.95	26.59
03/17/1811	1	20.25	72.28	0.62	10.22	72.32	3530.28	3524.57	0.02121	53.99	130.81	13.75	29.15
03/17/1813	2	12.71	72.66	0.64	10.89	72.70	3468.10	3462.51	0.02352	59.89	136.21	14.57	28.65
03/17/1815	2	13.75	72.98	0.69	11.77	72.98	3418.17	3418.17	0.02786	70.93	149.27	16.17	25.79
03/17/1816	2	16.75	73.36	0.83	14.31	73.36	3358.30	3358.30	0.04232	107.74	186.48	20.56	20.09
03/17/1817	2	14.75	73.74	0.75	12.60	73.67	3299.65	3310.22	0.03302	84.05	165.18	18.47	22.56
03/17/1819	2	17.75	74.05	0.90	15.14	74.12	3252.56	3242.20	0.04909	124.95	204.48	23.34	17.68
03/17/1820	2	19.75	74.75	1.01	16.81	74.75	3150.71	3150.71	0.06271	159.63	235.25	27.62	14.84
03/17/1821	2	15.75	75.06	0.84	13.41	75.06	3106.10	3106.10	0.04006	101.98	188.38	22.43	18.47
03/17/1822	2	20.75	75.61	1.07	17.65	75.61	3028.63	3028.63	0.07142	181.81	255.23	31.15	13.24
03/17/1824	2	21.75	76.86	1.07	18.54	76.76	2862.48	2875.91	0.08134	207.05	276.64	35.53	11.85
03/17/1825	3	16.75	78.00	1.07	19.59	78.00	2719.55	2719.55	0.09548	243.05	307.34	41.72	10.15
03/17/1826	3	17.75	78.69	1.07	20.80	78.38	2637.03	2673.79	0.10674	271.72	323.54	44.65	9.73
03/17/1827	3	18.75	79.73	1.07	22.02	79.14	2518.73	2584.97	0.14020	356.89	401.51	57.29	6.69

TABLE XII (Continued)

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
03/17/1829	3	19.75	80.94	1.07	23.23	80.32	2388.56	2454.48	0.14210	361.73	385.68	57.92	7.66
03/17/1829	3	19.75	80.94	1.07	23.23	80.39	2388.56	2447.05	0.14210	361.73	385.68	58.09	7.66
03/17/1830	3	20.75	82.53	1.07	24.45	81.53	2229.42	2328.22	0.16102	409.90	415.32	65.70	6.96
03/17/1831	3	21.75	83.88	1.07	25.66	83.26	2104.28	2160.97	0.18319	466.34	450.14	76.64	6.22

TABLE XIII

DATA FOR AGITATOR POWER REQUIREMENT TESTS WITH THE 4.039 INCH DIAMETER BLADE

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
06/22/1013	1	4.75	72.49	0.19	2.40	72.49	3496.20	3496.20	0.00073	1.85	19.14	2.03	319.26
06/22/1016	1	8.75	72.66	0.25	4.47	72.68	3468.10	3465.30	0.00264	6.71	37.23	4.06	151.25
06/22/1018	1	6.75	72.63	0.21	3.44	72.65	3473.70	3470.89	0.00148	3.76	27.03	2.94	221.19
06/22/1020	1	14.75	72.63	0.38	7.54	72.63	3473.70	3473.70	0.00804	20.46	67.25	7.31	78.24
06/22/1021	1	12.75	72.70	0.33	6.51	72.72	3462.51	3459.72	0.00590	15.02	57.11	6.23	93.76
06/22/1023	1	10.75	72.80	0.30	5.49	72.80	3445.80	3445.80	0.00415	10.57	47.69	5.23	113.28
06/22/1025	1	18.75	72.91	0.45	9.59	72.91	3429.19	3429.19	0.01292	32.89	84.93	9.35	62.46
06/22/1026	1	16.75	72.98	0.41	8.57	72.98	3418.17	3418.17	0.01034	26.32	76.13	8.41	69.41
06/22/1028	1	22.05	73.15	0.56	11.24	73.15	3390.80	3390.80	0.02016	51.32	113.15	12.60	41.21
06/22/1030	1	20.75	73.43	0.49	10.62	73.43	3347.54	3347.54	0.01606	40.88	95.38	10.75	54.81
06/22/1031	2	12.75	73.57	0.50	11.06	73.53	3326.16	3331.49	0.01723	43.86	98.23	11.13	53.85
06/22/1032	2	16.75	73.81	0.64	14.50	73.81	3289.12	3289.12	0.03041	77.42	132.27	15.17	38.93
06/22/1033	2	14.75	73.95	0.58	12.77	73.95	3268.17	3268.17	0.02364	60.17	116.68	13.47	44.08
06/22/1034	2	21.75	74.36	0.82	18.79	74.36	3206.25	3206.25	0.05232	133.18	175.57	20.66	28.65
06/22/1036	2	19.75	74.64	0.77	17.05	74.64	3165.75	3165.75	0.04423	112.59	163.57	19.49	29.96
06/22/1038	3	15.75	75.33	0.85	18.60	75.23	3067.08	3081.65	0.05369	136.67	182.04	22.27	26.39
06/22/1039	3	18.75	75.75	1.01	22.08	75.61	3009.62	3028.63	0.07753	197.36	221.40	27.55	21.18
06/22/1040	3	21.75	76.30	1.08	25.65	76.10	2934.96	2962.70	0.10641	270.89	261.58	33.27	17.64
06/22/1041	23	13.75	77.14	1.08	28.85	77.14	2827.03	2827.03	0.13723	349.34	299.96	39.95	15.09
06/22/1042	23	16.75	78.66	1.08	35.17	78.52	2641.08	2657.38	0.21069	536.34	377.71	53.48	11.62
06/22/1043	23	19.75	80.60	1.08	41.50	80.43	2424.92	2443.34	0.30457	775.30	462.76	71.17	9.14
06/22/1045	23	21.25	83.36	1.08	44.66	83.36	2151.40	2151.40	0.38003	967.41	536.54	93.55	7.33
06/22/1046	123	18.25	87.51	1.08	48.59	87.51	1806.81	1806.81	0.49354	1256.37	640.51	132.63	5.61
06/22/1054	23	8.75	99.35	1.08	18.31	99.55	1130.44	1121.67	0.10895	277.33	375.30	124.25	6.20
06/22/1055	23	11.75	100.24	1.08	24.63	100.41	1093.04	1086.03	0.19861	505.59	508.46	173.77	4.55
06/22/1056	23	14.75	101.27	1.08	30.96	101.27	1051.75	1051.75	0.29667	755.20	604.29	213.13	4.05

TABLE XIII (Continued

DATE	NW	XLA	TW	TF	T	TEAVG	VISW	VISB	HP	QAGIT	AGRPM	RER	PN
06/22/1057	23	17.75	103.67	1.08	37.28	104.36	962.57	938.81	0.42785	1089.15	723.63	285.38	3.41
06/22/1059	23	20.45	107.10	1.08	42.98	108.81	850.66	800.70	0.59323	1510.12	870.41	401.34	2.72

APPENDIX E

ACCOUNTING FOR AXIAL HEAT CONDUCTION IN THE EXCHANGER WALL IN CALCULATING THE EXPERIMENTAL HEAT TRANSFER COEFFICIENT

Mathematical Development

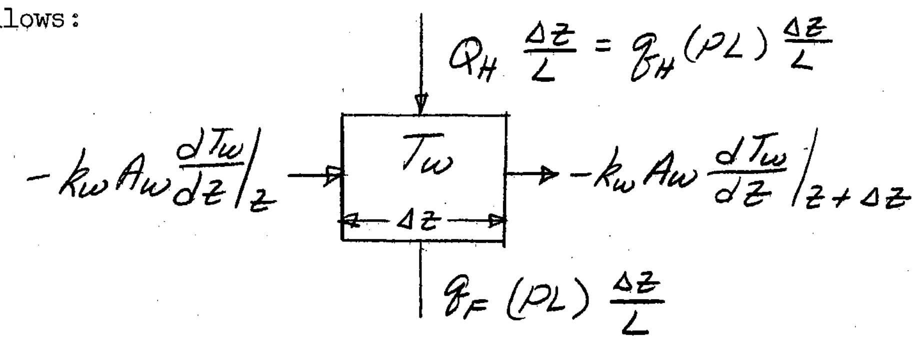
The following assumptions will be made:

(a) Radial temperature gradients can be neglected.

(b) The heat flux to the outside exchanger wall from the electrical heating element is axially constant.

(c) The thermal conductivity is axially constant.

With these assumptions a heat balance on an axial differential element of the exchanger wall, which is shown schematically below, is as follows:



$$q_H \Delta z - k_w A_w \frac{dT_w}{dz}\Big|_z + k_w A_w \frac{dT_w}{dz}\Big|_{z+\Delta z} - q_F \Delta z = 0 \qquad \text{(E-1)}$$

After dividing through by Δz , allowing Δz to approach zero and rearranging, the following relationship is obtained:

$$\frac{q_F}{q_F} = 1 + \frac{k_w A_w}{q_H P}\left(\frac{d^2 T_w}{dz^2}\right) = 1 + \frac{k_w A_w L}{Q_H}\left(\frac{d^2 T_w}{dz^2}\right) \quad \text{(E-2)}$$

The heat flux from the electrical heating element (q_H) has been assumed axially constant; therefore, it can be obtained from the electrical power measurements. P, k_w and A_w are known, thus it remains only to calculate the second derivative of wall temperature with respect to axial distance $\frac{d^2 T_w}{dz^2}$ in order to obtain the heat flux from the inner exchanger wall to the test fluid.

Before proceeding to calculating $\frac{d^2 T_w}{dz^2}$, equation (E-2) will be simplified by putting in known quantities.

Now

L = 22 inches

k = 116 Btu/hr ft F (for 6060 aluminum)

A = 2.718 square inches

P = 12.75 inches

With these substitutions equation (E-2) becomes:

$$\frac{q_F}{q_H} = 1 + \frac{4.014}{Q_H}\frac{d^2 T_w}{dz^2} \quad \text{(E-3)}$$

Calculation of $\frac{d^2 T_w}{dz^2}$ from Experimental Wall Temperature Data

There are two obvious possibilities for calculating $\frac{d^2 T_w}{dz^2}$: The first is to plot T vs. z on linear graph paper, obtain $\frac{dT_w}{dz}$ by using a straightedge, then plot $\frac{dT_w}{dz}$ vs. z on linear graph paper and then obtain $\frac{d^2 T_w}{dz^2}$ by using a straightedge. The second obvious method is to use difference technique on the experimental temperatures. It is also obvious that the difference technique can be applied to the experimental data by use of the digital computer, whereas the graphical technique cannot be done by digital computer.

Both techniques have been used and compared on typical selected data. The data selected for the comparison were a series of runs for the 3.500 inch diameter blade. Data for this blade were selected because the variation of heat transfer coefficient with exchanger length was probably greater in the laminar regime for this blade diameter than any other blade diameter, thus the correction for axial wall conduction was greatest for the 3.500 inch diameter blade in the laminar regime.

The wall temperature profiles for the selected data are plotted in Figure 32. The data are in the creeping flow and lower transition regimes. $\frac{dT_w}{dz}$ which was obtained graphically is plotted vs. z in Figures 33 and 34. $\frac{d^2T_w}{dz^2}$ which was obtained graphically is plotted vs. z in Figure 35 for one-half the selected runs. $\frac{d^2T_w}{dz^2}$ exhibits large axial variations near the exchanger ends (0 to 6 inches and 18 to 22 inches) but relatively small axial variations in the exchanger middle. For this reason, calculations of heat transfer coefficients near the exchanger ends or performing any other calculations which would involve using the second derivative near the ends would lack sufficient accuracy to be helpful in interpreting the data or in determining the accuracy of the wall temperature profiles.

The inaccuracy of the second derivative near the ends is of little concern for this investigation because it is desired to obtain a local heat transfer coefficient which is influenced as little as possible by the exchanger ends. It appears from these data that the location $z = 14$ inches might be the best axial location at which to compute a

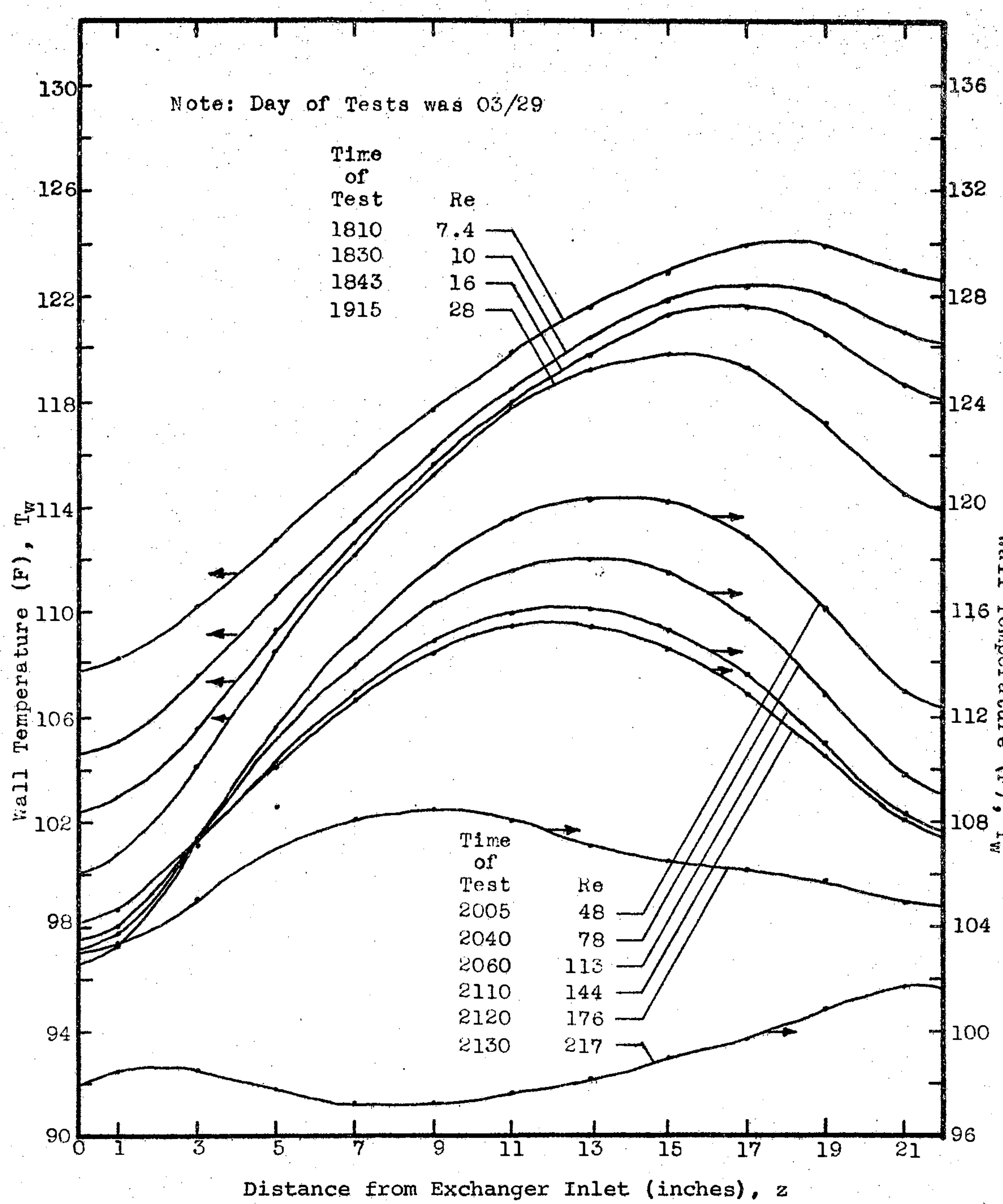


Figure 32. T_w vs. z for Selected Tests with the 3.500 inch Diameter Blade

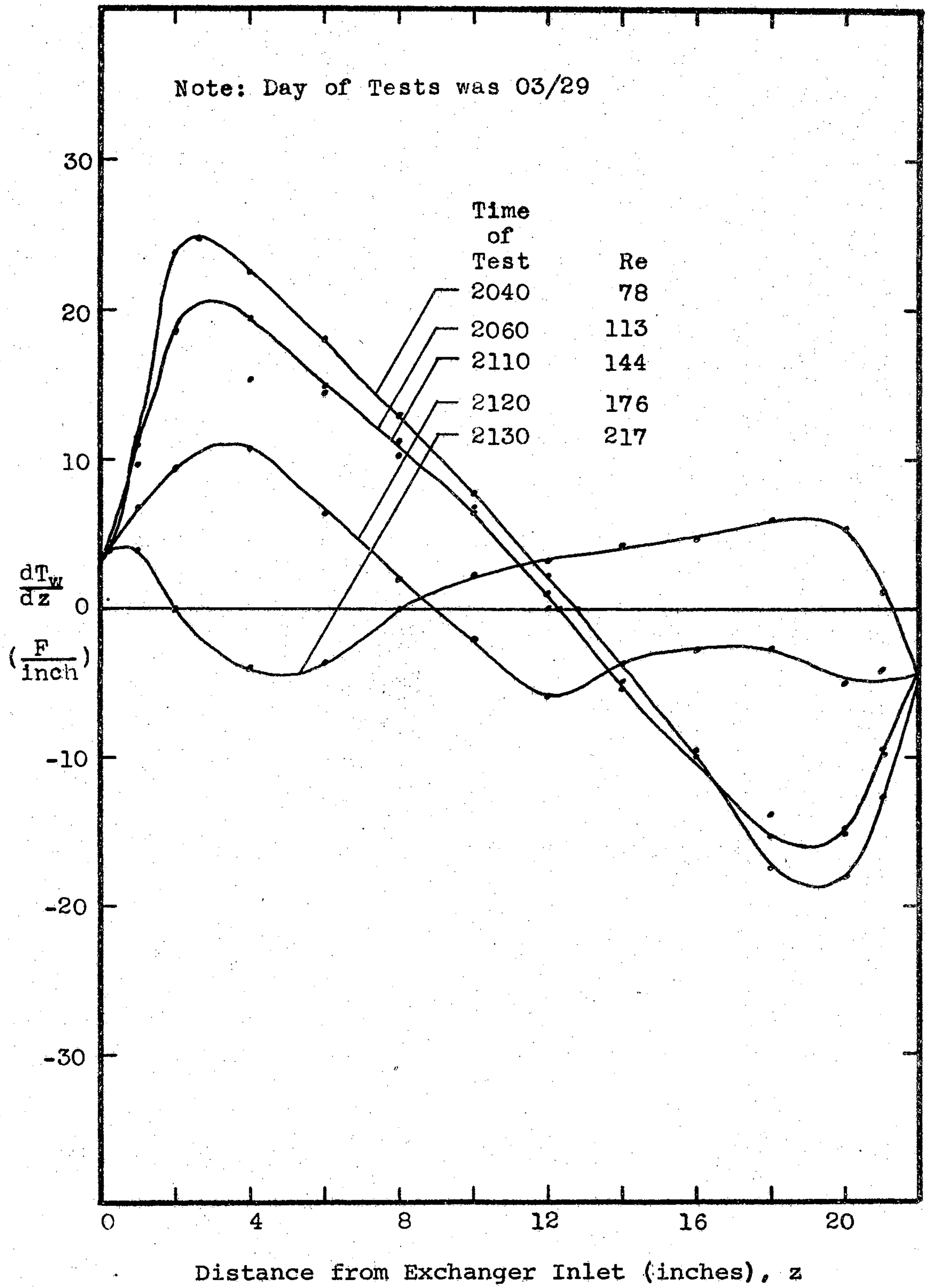


Figure 33. $\frac{dT_w}{dz}$ vs/ z for Selected Tests with the 3.500 inch Diameter Blade

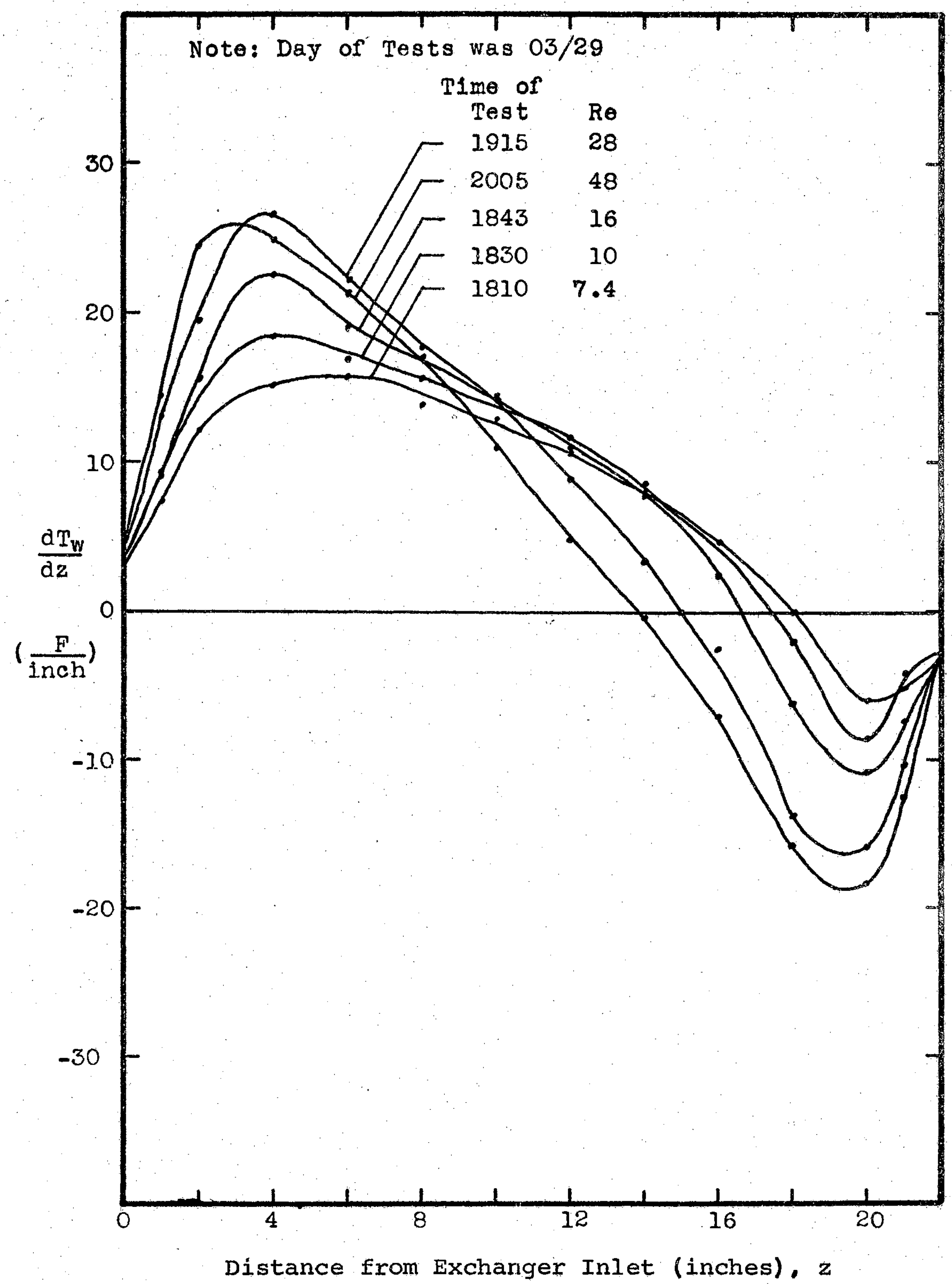


Figure 34. $\frac{dT_w}{dz}$ vs. z for Selected Tests with the 3.500 inch Diameter Blade

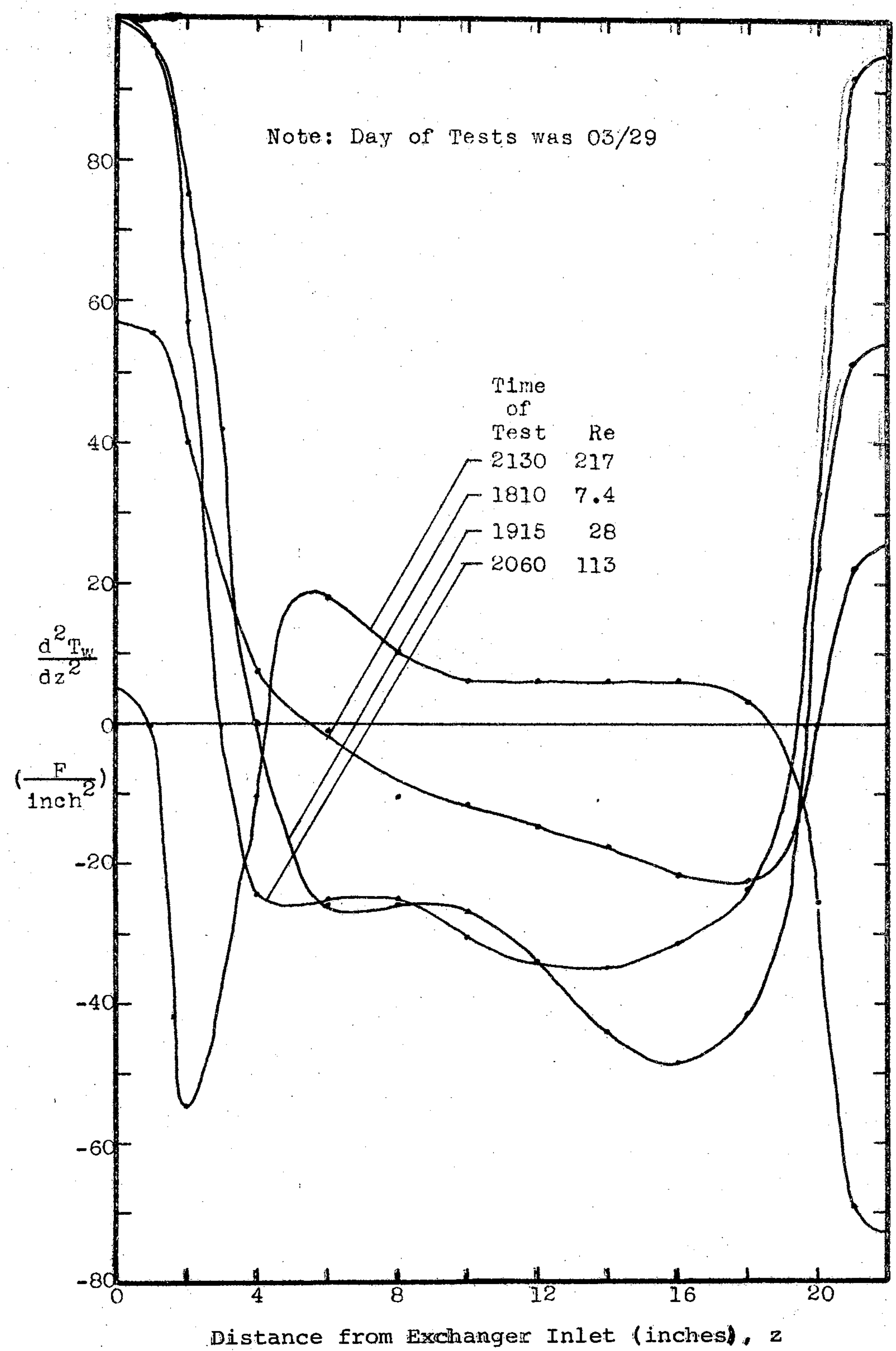


Figure 35. $\frac{d^2T_w}{dz^2}$ vs. z for Selected Tests with the 3.500 inch Diameter Blade

local heat transfer coefficient; the second derivative is nearly axially constant at this location which should be conducive to an accurate derivative; and the wall temperature profiles peak in the laminar regime near this axial location which indicates that the heat transfer coefficient may be affected the least by end effects at this location.

It should be noted that the axial location z = 14 inches is halfway between wall temperatures T_4 and T_5. The second derivative was calculated on the computer by taking the average of the numerically calculated second derivatives at thermocouple locations 4 and 5. The numerical calculation is as follows:

$$\frac{d^2T_w}{dz^2} = \frac{\left[\dfrac{\dfrac{(T_5-T_4)}{\Delta z} - \dfrac{(T_4-T_3)}{\Delta z}}{\Delta z}\right]_{z=14} + \left[\dfrac{\dfrac{(T_6-T_5)}{\Delta z} - \dfrac{T_5-T_4}{\Delta z}}{\Delta z}\right]_{z=14}}{2}$$

$$\left(\frac{d^2T_w}{dz^2}\right)_{z=14} = \frac{T_3+T_6-T_4-T_5}{2\,(\Delta z)^2} \qquad \text{(E-4)}$$

It was found that this method of numerically calculating the second derivative gave much more consistent results than calculating the second derivative numerically at a particular axial location at a thermocouple; however, the average results were about the same when compared on a plot of q_F/q_H vs. Re for a particular series of runs.

The graphical second derivative at z = 14 inches and the numerically calculated second derivative were both used to calculate $(q_F/q_H)_{z=14}$. Table XIV presents a comparison of $(q_F/q_H)_{z=14}$

calculated by the two methods. The maximum deviation of the graphical calculation from the numerical calculation is 7.5 percent for test number 03/29/1843 and the other deviations are less; the average absolute deviation between the hand and numerical methods is 2.4 percent.

This good comparison indicates that the numerically calculated second derivative is acceptable. This was the method used to obtain the local heat transfer coefficient taking into account axial wall conduction.

TABLE XIV

COMPARISON OF GRAPHICAL AND NUMERICAL METHODS OF CALCULATING q_F/q_H AT $z = 14$ INCHES FROM THE EXCHANGER INLET

Time of Test	Re	q_F/q_H	
		Graphical Method	Numerical Method
1810	7.4	0.86	0.86
1830	10.1	0.78	0.82
1843	15.7	0.74	0.80
1915	27.8	0.73	0.75
2005	48.1	0.73	0.72
2040	78.6	0.71	0.70
2060	113.5	0.73	0.74
2110	144.4	0.73	0.76
2120	176.9	1.12	1.12
2130	218.8	1.04	1.03

VITA

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Doctor of Philosophy

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