Studies on Impeller Design on Power Consumption from Temperature Rise Data In a Stirred Tank

Damaraju P. Rao and Chander S. Mahey. Chemical Engineering, Indian Institute of Technology, Delhi, Hauz Khas, New Delhi, India

The power input to a mixer is dependent on the impeller type, its rotational speed, the physical characteristics of the processed materials, the shape of the tank and the relative locations of its components such as the baffles, impeller etc. and more importantly the amount of dispersed phase fraction such as solids or an immiscible liquid phase. Reduction in the power consumption is a key requirement of the industry to make it competitive and cost effective. In the present work, it was proposed to study power input measurement from temperature rise data and also study the mixing and power input performance of the modified hydrofoil impellers made by CME engineers to reduce power consumption by creating new impellers which are the modified versions of Hydrofoil impellers obtained by twisting 3 Bladed Hydrofoil impellers. For narrow blade hydrofoils, Power No is low for hydrofoils compared to other impellers. Typically, low power number (0.1–0.5) impellers generate mean flow whereas high power number impellers (>3) generate flow having more turbulent kinetic energy. Accurate estimation of the power input required to obtain the desired performance of mixing equipment is crucial for successful design of the mixing equipment., **Panja and Rao** (1) investigated a new technique to determine the power input from measured data on rate of temperature rise due to the stirring of a liquid or a gas-liquid system in a 16 cm diameter mechanically agitated tank having standard tank configuration.. The change in the temperature due to stirring was continuously measured by using a thermopile consisting of two hot and two cold junctions and the power input was calculated from known heat capacities of the liquid, the reactor vessel and the stirrer and the measured rate of temperature rise by using the following energy balance equation

$$(m_w C_{pw} + m_r C_{pr} + m_s C_{ps})\Delta T / t = P \qquad (1)$$

where

m_w=Mass of water
C_{pw} =Specific heat of Water
m_r= Mass of wetted reactor
C_{pr} =Specific heat of reactor
m_s= Mass of stirrer+shaft+shaft support+ Baffle
C_{ps} = Specific heat of stirrer
DT = Temperature rise in ^{0}C in a time interval , t sec.

1. In the above equation, it is assumed that there are no heat losses from the reactor to the surroundings and also that reactor body, stirrer and the reactor fluid are at the same temperature as that of the reactor. The above assumptions are best realized if the initial temperature of the reactor is chosen same as the temperature of the

surroundings and small temperature rises can be accurately measured and if the rate of heat losses are small compared to rate of heat generated due to stirring and heat capacity of liquid is large compared to that of the walls. In addition to applying the temperature rise method, it was also proposed to measure electrical power input with and without water taken in the tank from the display screen of AC drive by pressing the up and down key and estimate mechanical power input to the tank..

DESCRIPTION OF THE EXPERIMENTAL SETUP AND PROCEDURE

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A complete sketch of the experimental setup is given in Figure 1 and a brief discussion of the various components that are used in the setup are given in Table 1

- The experiments in the present work have been carried out with an agitated cylindrical vessel made of Perspex. The vessel is equipped with an opening in the top cover for charging the required quantity of liquid and/or solids. The height of the liquid level in the tank is kept at 49 cm. Soft water is used in the power consumption studies . There are four baffles inside the tank to avoid any vortex formation while operating at high velocities. A drain at the bottom corner is provided to facilitate easy draining of the products.
- The measurements were carried out within the turbulent regime of the fluid flow in the vessel (*Re 5**10^5 to 1*10^6).
- RO water at temperatures around 25°C was used. The temperature rise was measured with the help of 4/4junctions thermopile. The agitator speed was set by means of AC drive provided by Dan Foss.
- Runs were made at different stirring rates of a blade with and without solids (PVC granules) for measuring power consumption .

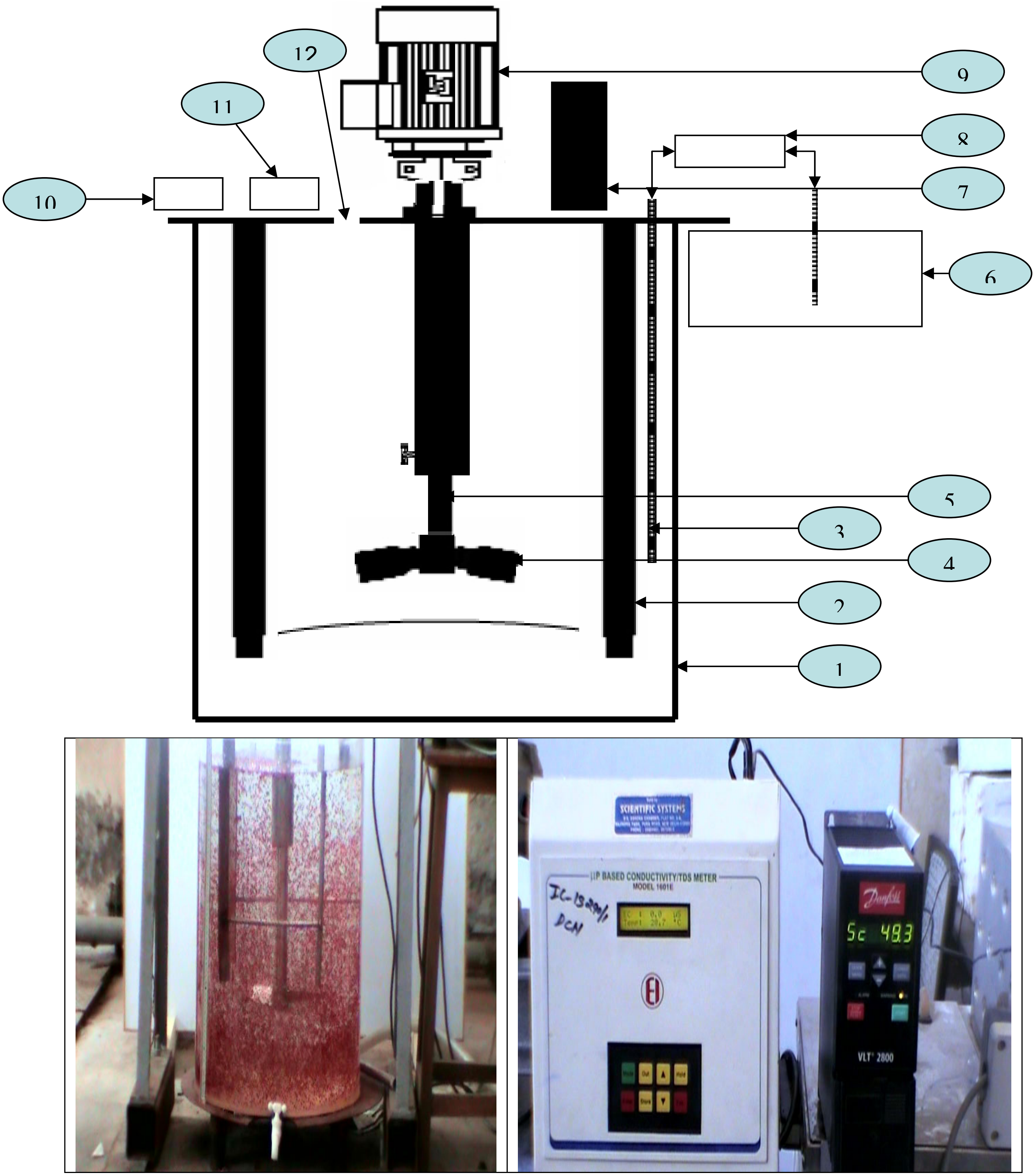
Experimental Procedure for the determination of Power Consumption

2. The tank is filled with water by using a water pipe through the opening at the top of the vessel. The water level in the tank is maintained equal to the diameter of the tank. To study the effect of solids, PVC granules of required weight are added in the water taken in the tank for making a predefined % solids loading.
3. After the tank has been filled up to the required level, the temperature of the water in the vessel is recorded by using a thermopile consisting of four hot junctions and four cold junctions and a digital micro-voltmeter connected to the thermopile wires,.
4. The reference junction of the thermocouple is inserted into the water bath which is maintained at constant temperature and the other is inserted into the tank.
5. The value of voltage developed by the thermopile is recorded at fixed interval of time
6. The stirring is continued at a fixed number of rotations per minute for a required length of time. The regulator knob in the VFD drive is rotated to get the required number of rotations per minute of the shaft. The number of rotations per minute is displayed on the display screen of drive and is noted down.
7. During the run it must be ensured that the variation in the number of rotations per minute should not deviate by more than 2%.
8. At the end of a run, the motor is switched off and either water is allowed to cool or is drained and replaced.
9. The electrical power inputs with and without water taken in the tank are also measured by noting the value directly from the display screen of AC drive by pressing the up and down key.

10. The above steps are repeated at different stirring speeds in steps of 50 rpm and for different % of solids loading.

Table. 1 Design details of the tank

Equipment	**Specification**	
Tank(Perspex)	ID=490mm OD=500mm Height=910mm	
Solid Shaft(SS316)	OD=25mm Length=800mm Weight=4kg/m	
Shaft support(SS316)	OD=50mm ID=44mm Length=550mm Weight=3.11kg/m	
Impeller(SS316)	Hydrofoil impeller(Blade1,2,3,4)	
4 Baffles(SS316)	Thickness =3mm Length=725mm Width 450mm	
Stainless steel lid	Provided with water inlet, thermocouple inlet and conductivity probe inlet	
Tank Stand	Circular stand of height =10.5 cm	
Electric Motor	Hindustan electric motors,1 HP,3P, 415 V,2A,75% efficiency	
Motor controller drive	Danfoss, VLT 2800 series	
Conductivity Meter	Global DCM900	
Conductivity cell	Cell cons.=1.0	
Digital multimeter	Sanwa,PC5000	
Thermocouple	Constantan Chromel (E type)	2 junction thermocouple supplied by K.M.Instruments,sensitivity=0.05263mV/C 4 junction thermopile made in our lab, sensitivity=0.1265mV/C
Water bath	Julabo,Model ME	
Temperature controller	Audiotronics (with RTD Probe)	
Humidity meter	Instron 1003	
Personal Computer and UPS		



1.Flat Bottom Tank, 2.Baffles, 3. A 4 junction Thermopile, 4.Hydrofoil Agitator, 5. Motor Shaft, 6. Water Bath, 7. Motor Controller drive, 8. Digital Multimeter, 9. 3P Electric Motor, 10. Temp. Controller, 11. Humidity Meter, 12. Inlet port

Figure .1. Schematic diagram of Experimental Setup

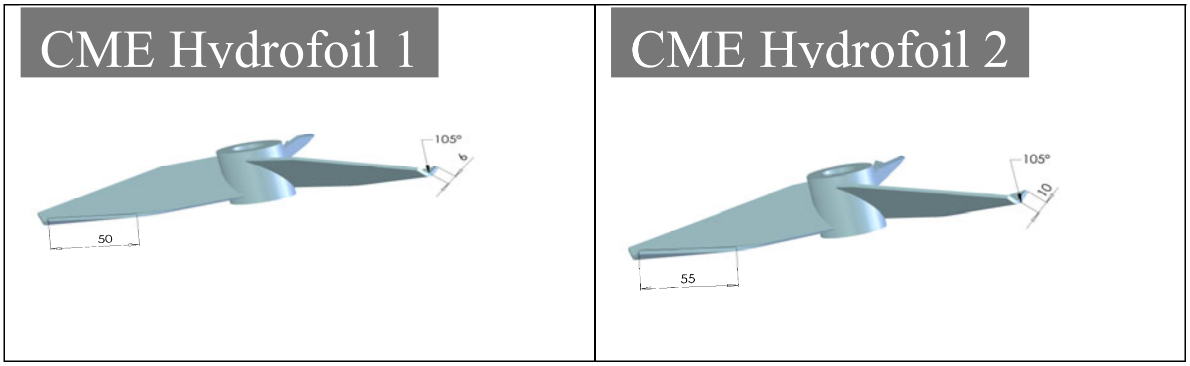


Figure 2. Impellers used for study

.Calculation of power input from rate of temperature rise of tank fluid was done by using the following relation:

$$P = (m_w C_{pw} + m_r C_{pr} + m_s C_{ps}) \Delta T / t$$

where
Mass of water=92.128kg
Cp =4.1855 KJ/(KgC)
Mass of wetted reactor=7.22 kg
Cpr =1.27 KJ/(KgC)
Mass of stirrer+shaft+shaft support+ Baffle=0.4+3.2+1.71+3.5=8.81kg
Cps =0.494 KJ/(KgC)
P=399.123*ΔT/time, Watts
Figure 3 shows a typical run showing thermocouple emf recorded as a function of time which shows that raise in tank temperature is linear with respect to time.

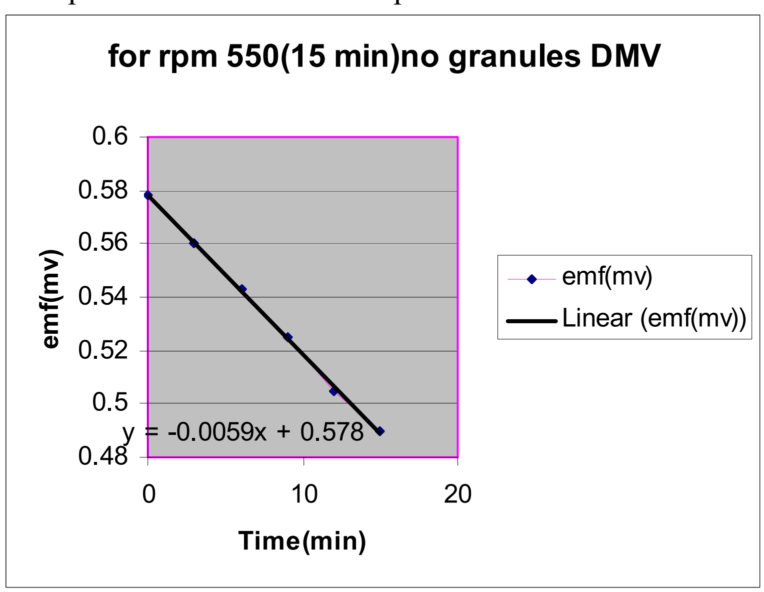


Figure 3. Thermopile voltage as a function of time for blade No. 1

The sample calculations for power input for the data shown in Figure 3 are given below:

Sensitivity of thermopile = 0.268 mV/C
Total run time =15 min
Reference temp.=32.5°C
Rpm=550
Calculation:
Slope=0.0059mv/min
Rate of temp. Rise= Slope (mV/min)/ sensitivity of thermopile (mV/^{O}C)
=.3.669×10^{-4}°C/sec
P=399.123×10^{3}× 3.669×10^{-4}
=146.4W
Power consumed by motor with water inside the tank (AC drive) =230W
Power consumed by motor without water inside the tank =70W
Net electrical power input corrected for electrical and mechanical energy losses in the motor=160W

Accuracy analysis

Error in measurement in temp rise method

e1 = error in measuring initial temp T1 in terms of thermoemf in μV

e2 = error in measuring final temp T2 in terms of thermoemf in μV

Max error = [(|e1|+|e2|)/(/Δe)]X 100%

Least count of Microvolt meter = 1μV

Δe = Measured change in thermopile voltage over a time interval t sec..

The relative error in power input voltage change over an interval of time has been found to be between 2% to 10% .

Heat Capacity from Perspex tank & undipped part of stirrer in air.

= ((WCp)perspex tank +(WCp)hanging stirrer))/WCp (total)

=((7.22X1.27)+(4 X 0.494)/399.123 X 100%

=2.79%

Error of measurement in Wattmeter

LC = 10 w , hence error could be [10/P] x 100%. Hence, the method of power input measurement by using wattmeter is reliable for P>100 W.

Tables 2-4 show the power input measured by using the method of temperature rise and net electrical power drawn as a function of stirring rate obtained by using the three impellers.

Table 2. Power Measurement for CME hydrofoil impeller 1

RPM	Time (Min.)	Method 1 (Net electrical power consumed in mixing) in Watts	Method 2 (Power from temperature rise data) in watts
350	15	40	25.1
400	15	60	49.89
450	15	90	99.7
500	15	130	119.73
550	15	160	146.4
600	15	190	182.43

Table 3.Power Measurement for CME hydrofoil impeller 2

RPM	Time (Min.)	Method 1 (Net electrical power consumed in mixing) in Watts	Method 2 (Power from temperature rise data) in watts
350	15	30	27.30
400	15	60	54.60
450	15	90	84.39
500	15	100	89.35
550	15	150	136.51
600	15	180	166.33

Table 4. Power Measurement for PTD impeller

RPM	Time (Min.)	Method 1 (Net electrical power consumed in mixing) in Watts	Method 2 (Power from temperature rise data) in watts
350	15	100	91.8
400	15	140	124.11
450	15	200	178.71
500	15	290	275.39
550	15	380	374.79
600	15	490	474.03

Study on Effect of twist in hydrofoil impeller

A Comparison of power drawn found by using the temperature rise method for the three impellers corresponding to three agitation rates for water as the tank fluid is shown in Table 5

Table 5

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RPM	500	550	600
IMP 1	120.0	146.4	182.4
IMP 2	89.4	136.5	166.3
PTD	275.4	374.8	474.0

Results were obtained by varying solid loading of PVC particles from 0.1% to 0.4% but as the solid loading was very small, no significant change in power consumption was found.

CONCLUSIONS:

- Increase in twist of Hydrofoil impeller reduces Power consumption
- Power Consumption data measured by temp rise method and estimated from net electrical power input consumption were in reasonable agreement
- Power consumed was found to be increasing with increase in rpm.
- The Difference in the power input data obtained by using the two methods was of the order of 3% for higher rpm to 18% for lower rpm i.e the difference was found to be decreasing with increased power consumption
- Power Consumption for Hydrofoils having greater twist was lesser than Hydrofoils having lesser twist.
- Power consumption for CME hydrofoil blades was lesser than Standard Pitched blade turbine impellers
- The solid loading being very small as such , the change in power consumption due to solid loading could not be detected by the power meter

In the case of the temperature rise method, the power consumption data as a function of sold loading did not show any expected trend due to the following reasons:

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1. The heat capacity of solids is not added in the power consumption calculation. However, for low loadings , contribution by heat capacity of solids will be small.
2. But as the solids are thermally poor conducting type, there may be temperature gradients in the solids, and heat transfer from liquid to solid phase under transient conditions may be significant and hence the temperature probe may be registering a lower rate of rise with increase in solids. Hence further work is needed to modify the method of power input by temperature. rise method for solid -liquid systems.

REFERENCE

[1] N.C. Panja and D.P. Rao, Power input measurement from temperature rise data in mechanically agitated contractors, *Institution of Chemical Engineers*, (1992) 24-27.