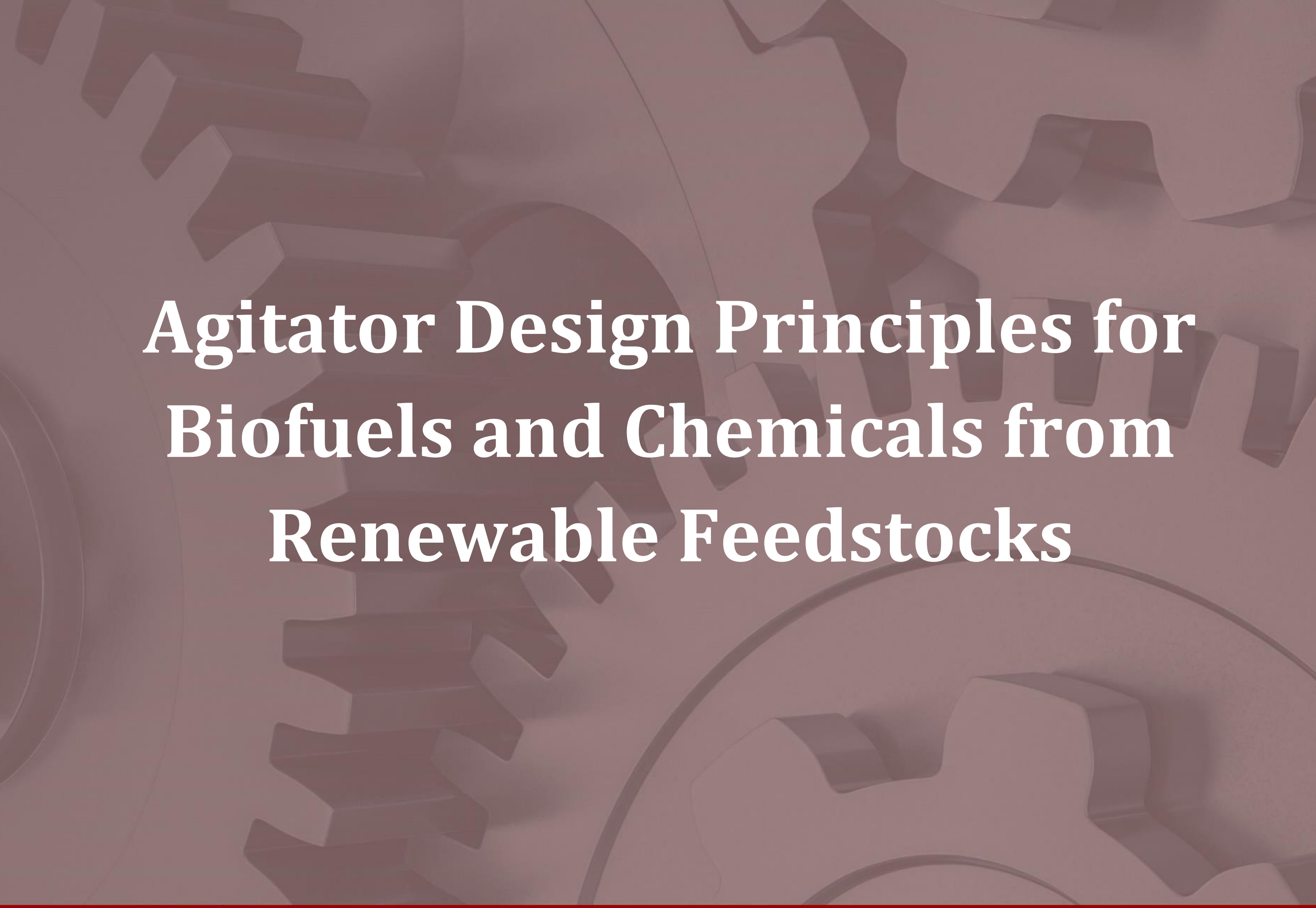

Agitator Design Principles for Biofuels and Chemicals from Renewable Feedstocks

An Online Continuing Education Course for Engineers

Course Number: M-8010
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Introduction

This course is intended to aid those in the biofuel and chemicals from renewable feedstock industries who must specify, purchase, operate, troubleshoot or perform research involving agitation equipment. Applications in these industries might include, for example, broth and slurry tanks, compounding tanks, hydrolysis tanks and fermenters/bioreactors. The application technology ranges from simple to complex, and the construction methods range from standard to highly sanitary. A basic Introduction to general agitator design principles is given, but the focus is specifically on applications found in the biofuels and biochemicals from renewable feedstock industries. Sanitary design will not be covered here.

The course begins with a basic introduction to agitation terminology and principles, then progresses through design concepts for liquid motion, common industry applications and scale-up. Time is devoted to rheology and agitation of fibrous materials, such as lignocellulosic feedstock, chemical cotton, etc. and its agitation challenges during hydrolysis. An introduction to advanced tools such as Computational Fluid Mixing (CFM) is given. Solids suspension is not covered, as serious solids suspension applications are rare in these industries, and are covered in more generic agitation courses available in the marketplace. Likewise, mechanical design is not covered, both due to time limitations and the availability of such information in more generic agitation courses. A special feature is discussion of vendor selection, and mistakes that have been made in the industry.

Chapter One: Agitator Design Basics

In this section, we will cover nomenclature, standard symbols, basic concepts, principle dimensionless numbers and the main classifications of flow patterns. We will also cover the basics of heat transfer calculations.

To begin, it is useful to identify the major components of an agitated tank, as shown in Figure 1. (Illustration by Benz Technology International, Inc.)

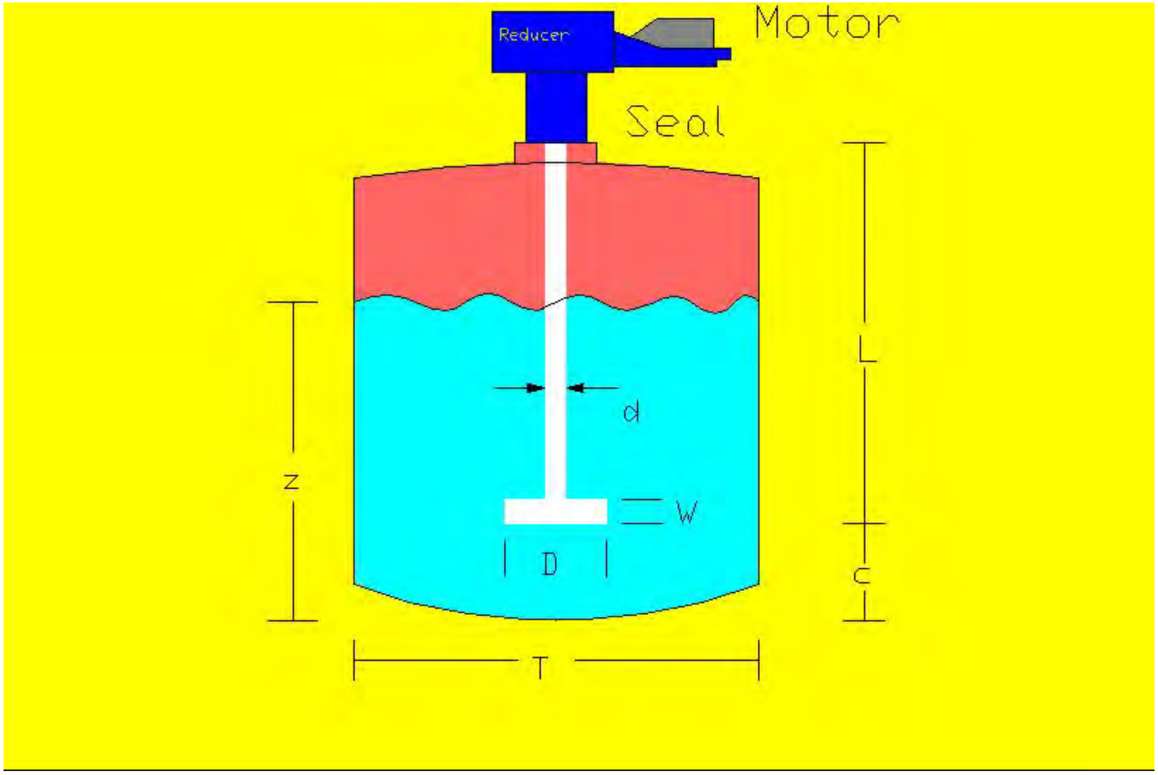


Figure 1. Typical agitated tank

Let us follow the flow of power through the system, identifying the nomenclature and standard symbols as we do so. Note that the term "agitator" refers to the entire machine (exclusive of the tank); some people incorrectly use this term to apply to the impellers.

Power is provided by means of a prime mover. Though any device which provides rotary power can in principle be used (the author has seen such things as hydrostatic drives, steam turbines and internal combustion engines in use as agitator power inputs), the most common prime mover is the simple electric motor. Most commonly, agitators are fixed speed, though multispeed motors or variable speed drives may be used where there is a need to change speed during different parts of the process, a desire to fine-tune results, or simply to minimize energy consumption.

In most cases, (except in small tanks, typically less than 2000l capacity) motor speed is too high to drive the shaft directly. Therefore, the power is transmitted through a speed reducer, which is normally a gear drive, though in some applications other drives, such as belts and sheaves, may be used. This reducer, in addition to reducing speed and increasing torque, must usually support all of the shaft loads, which include not only torque, but bending moment, downward load (weight) and pressure thrust in a closed tank. These duties are normally best served by using a gear drive specifically designed for agitator service, rather than a standard commercial speed reducer.

In many cases, the agitator is mounted on a closed top tank, so it will have a shaft seal. This may be lip, packing or various types of mechanical seal. Some agitators are mounted on open-top tanks, and do not have a seal.

The power is transmitted to the impeller or impellers by a shaft, with diameter “d” and extension “L” from the mounting surface. This shaft must transmit torque, withstand bending moment and not operate at a speed close to its natural frequency. In addition to solid, constant diameter shafts, agitators may have stepped diameter or even hollow shafts.

Agitation is created within the tank by the action of an impeller or impellers, turning at the shaft speed, “N”. Each impeller has a diameter, “D”, a blade width “W”, and an off bottom clearance, “C”.

Most agitated tanks have a cylindrical shape. The tank diameter is referenced by the symbol “T”, and the liquid level is referenced by “Z”. Other dimensions used to lay out the tank and agitator but not usually given standard symbols include the mounting height or nozzle projection, straight side and head depths.

There are some other important variables and symbols used in agitator design, not shown on the tank sketch. These include the impeller pumping rate, “Q”, liquid density, “ρ”, liquid viscosity, “μ”, and power draw, “P”.

These symbols are summarized below.

Symbol	*Meaning*	*Symbol*	*Meaning*
D	Impeller Diameter	N	Shaft Speed
T	Tank Diameter	L	Shaft Extension
d	Shaft Diameter	Q	Impeller Pumping Rate
C	Off Bottom Clearance	ρ	Liquid density
Z	Liquid Level	μ	Liquid Viscosity
W	Impeller Width	P	Power Draw

The complexity of agitated tank geometry makes analytical solution of the equations of continuity and the Navier-Stokes equation all but impossible. Progress has been made using numerical methods to solve these equations, but even these methods currently have limitations, which will be discussed in a later chapter.

The most common way to solve agitation problems is to correlate experimental data using expressions involving dimensionless numbers, and then use these correlations to solve a variety of real-world problems. The next several pages will cover the principal dimensionless numbers, their significance and how they are used.

Dimensionless numbers, as their name implies, are numbers derived from ratios of quantities such that all units cancel out. Therefore, any consistent set of units can be used; the equations do not depend on any particular set of units. For example, a very simple dimensionless number could be the aspect ratio of a cylinder, which could be represented by H/D, where H is its height and D is its diameter. It does not matter whether the height is measured in meters, inches or furlongs; as long as the diameter is measured in the same units as the height, the aspect ratio is the same. The units *must* cancel; a dimensionless number has no units.

In agitation technology, there are a number of dimensionless numbers which are in common use. These include:

- Power Number, N_P
- Pumping Number, N_Q
- Reynolds Number, N_{Re}
- Froude Number, N_{Fr}
- Nusselt Number, N_{Nu}
- Prandtl Number, N_{Pr}
- Geometric Parameters: D/T, C/D, etc.

Below we will explain these in more detail.

1. Power number, N_P

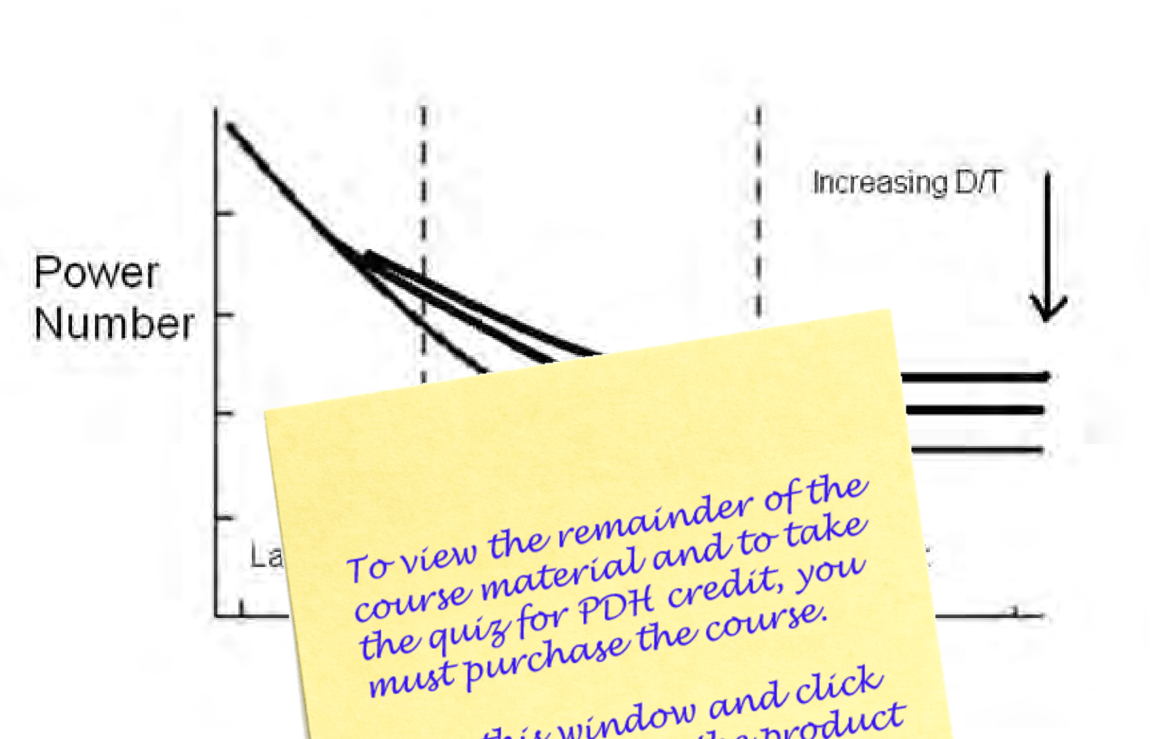
This is defined by $N_P = P/\rho N^3 D^5$

It is proportional to the ratio of power draw to liquid density and impeller parameters, including shaft speed. Its principal use is to calculate power draw. As such, it is used in all agitator designs. It is a function of impeller type, Reynolds number and various geometric parameters, such as off bottom clearance to impeller diameter ratio (C/D) and ratio of impeller diameter to tank diameter (D/T).

At high Reynolds numbers (low viscosity), it becomes constant, indicating that for turbulent flow, power draw is directly proportional to liquid density, the cube of shaft speed and the fifth power of impeller diameter.

At low Reynolds numbers (high viscosity), the power number becomes inversely proportional to Reynolds number and the geometric effects disappear. This means that in laminar flow, power is independent of density but is directly proportional to viscosity, shaft speed squared and impeller diameter cubed.

A conceptual Power Number versus Reynolds number curve is shown in Figure 2. (Illustration by Benz Technology International, Inc.)



Power numbers have bee ent manufacturers do not always publish such a table listing some turbulent power numbers /T. (We will define these impeller types later accompanying this course. (Illustration by Benz Tech , Inc.)