Specific power for mixing

INTRODUCTION

Old rules of thumb and mixer design methods based on mixing power intensity today still circulate in the waste water industry. A critical review reveals that alleged required levels of mixing power intensity, expressed in for instance W/m^3, $hp/10^3$ or 10^6 US gal, or $hp/1000\ ft^3$, are not well-defined. Furthermore, they are based on a variety of mixing technologies and out-of-date mixing requirements. Designing mixers with a momentum approach and using Flygt submersible mixers or top-entry agitators is shown to require only a fraction of these intensities in for instance biological treatment and sludge handling.

WHAT IS MEANT BY POWER AND SPECIFIC POWER?

In the mixing context, specific power (sometimes "power density" or "power intensity") is usually referred to as the mixer power per unit volume of process liquid in the mixed tank. But power is a multi-faceted concept. While horsepower (hp) should normally refer to shaft/brake power, either rated or actual, the international standard unit Watt (W) for power may be used for any of the facets of power. (In the USA, shaft power is typically not expressed in W.) Among these we also find electric power, either rated or actually consumed, and hydraulic power. The latter may be defined to be associated with only the liquid pumping of a mixer, or it may include shearing power, swirling power, etc. Different powers are schematically illustrated in Figure 1.

Usually the actual power is less than the rated value by some service factor that allows for process variations and increases the life of the mixer. This applies to the shaft and electric powers alike.

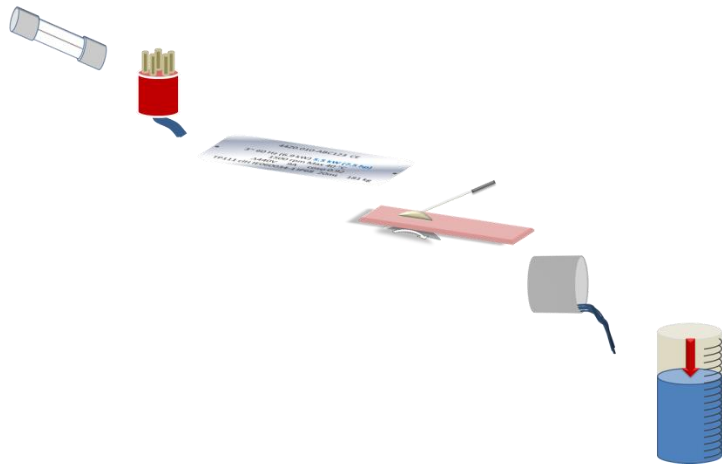

Figure 1. Power entities, from top left to bottom right. (1) Electrical installation max amps and related power (2) actual wire power (3) rating = plate value (4) actual brake/shaft power (5) total hydraulic power (6) useful hydraulic power.

The different powers are measured or determined in completely different ways. Some of them may be relevant but are not easily measured and are therefore not routinely mentioned in technical documentation. For axial flow mixers, the thrust value (see below) offers an elegant solution to this dilemma.

The ratio of two different powers is a dimensionless efficiency, usually denoted by the greek letter (eta). For instance, the total or *wire-to-water efficiency* of a pump is given by its well-defined hydraulic power divided by its actually consumed electric power. Whatever shaft or other power that happens to be printed on plates does not enter the definition.

Because units of volume also vary, the unit for power per volume varies considerably between users in the USA. Units commonly used for specific power include those given in Table 1, where conversion factors are also given.

Table 1. Specific power units commonly used in mixer specifications today. Note that conversion presupposes a consistent power definition, see Figure 1.

Convert from	**Convert to by multiplying**			
	W/m^3	**hp/1000 US gal**	**$hp/10^6$ US gal**	**$hp/1000\ ft^3$**
W/m^3	**1**	**0.0051**	**5.1**	**0.039**
hp/1000 US gal	**194**	**1**	**1000**	**0.134**
$hp/10^6$ US gal	**0.19**	**0.001**	**1**	**0.00013**
$hp/1000\ ft^3$	**26**	**7.5**	**7481**	**1**

This discussion shows that although power is a familiar concept, there is much room for arbitrariness in defining power and specific power in technical specifications. It is argued below that in the wastewater industry the actually consumed electric power is generally the most relevant candidate, because its value should mainly be used to describe wire-to-water efficiency.

POWER SPECIFICATIONS FOR WASTEWATER MIXING

A number of sources have been consulted for general recommendations on specific mixing power. Staying clear of mixer suppliers, general literature and some statement from engineers in the USA constituted the core of the findings. These are given in Table 2.

Table 2. Citations on power density for mechanical mixing in wastewater taken from US based sources.

Metcalf & Eddy (international, fourth edition, 2004)	
"… completely mixed flow … with mechanical aerators … from 20 to 40 $kW/10^3\ m^3$"	20 – 40 W/m^3
"Typical … mechanical mixing in the anoxic zone … 8 to 13 $kW/10^3\ m^3$"	8 – 13 W/m^3
"Typical design parameters for anaerobic digester … Mechanical systems … 0.005 – 0.008 kW/m^3 …"	5 – 8 W/m^3
"Design criteria for aerobic digesters …Energy requirements for mixing: Mechanical aerators … $kW/10^3\ m^3$ 20 – 40"	20 – 40 W/m^3
WEF Manual of Practice 8 (1998) – no data	
WEFTEC 2013, Carollo Engineers & City of Woodland, California	
"30 to 100 hp per million gallons …"	6 – 20 W/m^3

The recommendations cited in Table 2 partly refer to mixing by mechanical aerators (20-40 W/m^3). The efficiency of any generation of mechanical aerators for mixing need not be discussed in detail here. It is noted that simultaneous mixing and aeration is a very common operation. Mechanical surface aerators usually come with a certain depth and range of influence, and an oxygen transfer capacity. Sizing and clustering of these units leads to some interval of specific power to accomplish both oxygenation and mixing.

Bottom diffused aeration for BOD removal and nitrification has been associated with air flow rates per tank volume, per treated volume of sewage or per tank bottom area. A few limits on air flow rate per bottom area have been given to ensure sufficient mixing by such aeration systems [MHB]. Transforming these guidelines into specific power, they typically indicate some 5-10 W/m3, depending on liquid depth and upstream mechanical treatment.

Returning to Table 2, the origin of statements in the range of 5-20 W/m^3 for non-aerating mechanical mixers is of interest. (The 8-13 W/m^3 interval has been overheard elsewhere as a "generally accepted level for submersible mixers".)

The inclination of engineers to focus on energy efficiency rather than conservative robustness has increased over time, though at a different pace in different parts of the world. Upstream processes such as preliminary and primary treatment have been introduced and/or trimmed over the years, resulting in reduced requirements on solids suspension in biological treatment and secondary sludge tanks. Finally, it cannot be ruled out that mixing equipment efficiency has improved over the decades.

These circumstances are probably sufficient to lead from the figures given in Table 2 to today's considerably lower specific power need in wastewater and sludge mixing operations.

As will be discussed in the next two sections, sizing of mechanical mixers for wastewater and sludge systems preferably takes a route different than specifying the power. Depending on the process itself, the upstream process and the mixing tank design, the power requirement may vary by an order of magnitude.

BASIS OF MIXER SIZING

The hydrodynamic target for a mixing system is typically a bulk flow encompassing the whole volume to secure blending and reaching some minimum velocity near the tank floor and in the vertical to secure solids suspension and distribution.

Mechanical mixing systems with submerged or top-entry axial flow impeller mixers can be designed for this target using a momentum approach. This has been the Flygt approach for decades [MHB], and it also underlies the international ISO 21630 (2007) standard for testing of submersible mixers. A recent independent publication [Machado & Al] names the momentum an entity of major importance for agitated tank processes.

The momentum issuing from the impeller discharge each second is a measurable entity. This is the thrust, which is a force equal to the reaction force from the liquid onto the mixer. Thrust data, as published by Xylem, are thus the basis on which mixer selection is made.

Thrust may be understood using an analogy with a propeller ship. The ship speed is a result of the thrust exerted by the propeller. Similarly, the liquid velocity in a mixed tank is a result of the thrust of the mixer. (Consider what happens to the water if the propeller is running while the ship is fixed in a dock.) The higher the thrust, the higher the velocity is reached in both cases. For a given thrust, the magnitude of the attained velocity depends on the ship/tank design.

The many reasons impeller speed per se, mixer flow rate or power are less useful as design parameters for flow controlled mixing are discussed in the Flygt Handbook of Mixing. Mixer flow rate and power are sometimes poorly defined. It remains a fact that with thrust as a well-defined and measurable parameter, mixers of different designs may easily be compared performance-wise.

It is natural to favor the mixer that produces the required thrust at the lowest power consumption. Indeed, the thrust per input power (N/kW) is the mixer efficiency parameter proposed in ISO 21630. Though it is not dimensionless, it is a true wire-to-water characteristic.

WHAT POWER IS REQUIRED WITH FLYGT MIXERS?

In biological treatment systems, the mixer power density required for Flygt submersible mixers or top entry agitators usually falls within 1 – 5 W/m^3. As argued above, this refers to the actually consumed electric power. The reason for the span width lies in a number of factors: tank shape, sewage pretreatment, outlet position, through flow rate, etc. In oxidation ditches the design and intensity of aeration will also influence the power requirement.

In sludge storage or digesters, the mixer power density required for Flygt submersible mixers or top entry agitators usually falls within 1 – 10 W/m^3. The consistency of the sludge at higher solids concentration or with polymer additives may actually call for even higher power in some cases.

Table 3. Typical specific power need for Flygt mixers in some waste water treatment operations.

Process / liquid	Flygt mixing specific power need (W/m^3)
Activated sludge	1-5
Primary or waste activated sludge	1-5
Thickened sludge > 5%	5-10
Moving bed bioreactor (MBBR)	3-10

Another reason for the variation in power requirement is the variation in mixer characteristics. Laws of nature require more power to generate a certain thrust using a small high speed impeller, than when using a large low speed impeller. Installation cost and versatility may be arguments to choose the former, whereas Life Cycle Cost often speaks for the latter. An intermediate size and speed mixer may provide the optimal balance in many instances. The intermediate solution may even minimize LCC in thickened sludge because of the effect of thick liquids on mixer performance.

Finally, the mixer or agitator design, motor and transmission efficiency, positioning/ installation and mode of operation have a substantial influence on the energy required for the job.

In the USA, the 1980s-1990s practice for Flygt mixers may well have been influenced by a strong conservatism. This in turn may have originated in older industry standards, or in more conservative requirements due to for instance less developed preliminary and primary treatment.

A good example of the evolution of power requirement is the Madison Metropolitan Sewerage District Nine Springs WTF. As a result of process improvements since the late 1990s, room for mixer power reduction emerged. Careful analysis of the mixing need showed that the electric power for mixing could be reduced to about 1/3 of what was initially installed when using the same type of mixers (small high speed). Today the specific mixer power is 4.4 W/m^3, a number which can be further greatly reduced by installing low speed mixers.

CONCLUSION AND SUMMARY

The take-away is that power intensity (W/m^3) cannot generally be used to assess *mixing capacity*, but may well be used to assess *mixing efficiency*.

Capacity refers to getting the mixing done. *Efficiency* refers to the energy consumption, assuming the mixing gets done.

Because power refers to efficiency, the only reasonable choice when stating a power density is the actual (not rated) electric power. This provides a sound basis for stating a wire-to-water efficiency.

For Flygt submersible mixers or top-entry axial impeller agitators, the wire-to-water power intensity required in biological wastewater treatment is commonly 1-5 W/m^3. For sludge handling, thickened sludge may require 5-10 W/m^3. Tank and process design are crucial factors in keeping the power requirement down.

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