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Advanced impeller design: Anti-ragging impeller, ARI2

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ABSTRACT

The waste water treatment plant anoxic denitrification process employs agitated vessels which contain process fluids contaminated with fibrous, rag-like materials that have a tendency to collect on impeller blades and adversely affect mixing performance. The existing Philadelphia Mixing Solutions Ltd. anti-ragging impeller made from fiberglass reinforced plastic is not cost effective for this low torque application. The challenge was to design an impeller that replicated the performance of the original impeller but utilized common industrial manufacturing processes to reduce cost. The flexible construction technology chosen was sheet metal fabrication. The design effort produced a highly skewed, forward raked, hydrofoil impeller with applications that extend beyond the waste water treatment industry. The performance of the new impeller was evaluated by comparing it to the fiberglass impeller as well as three other common impeller types used in stirred tanks. Impeller pumping capacity was measured using 2-D Particle Image Velocimetry and impeller power draw was measured using a load cell and tachometer. The characteristic dimensionless impeller power and flow number, Np and Nq, were computed to be 0.17 and 0.42, respectively.

Keywords: Anti ragging; Axial flow impeller; Fabricated metal impeller; Optimized impeller design; Water treatment; Waste water; Denitrification; Anoxic

1. Introduction

A new impeller has been created for the purpose of providing the most mixing for the least dollar cost. The specific process categories applicable to this new impeller are waste water treatment anoxic denitrification and anaerobic/aerobic digestion. Both processes can contain a significant quantity of stringy, fibrous, rag-like material (e.g., hair, textile, and paper fibers) that can accumulate on impellers that are not specifically designed for this type of service (Fig. 1). These string-like materials, whose lengths range from less than a centimeter to half a meter, are generally neutrally buoyant, and have escaped capture by pre-filtration steps.

Mixing impellers that resist the accumulation of rags are known as "anti-ragging". Philadelphia Mixing Solutions Ltd.'s first anti-ragging hydrofoil design was created in 1981, and revised in 1988. The third generation high efficiency fiberglass reinforced anti-ragging XELSC-2200 impeller was introduced in 2008 (Fig. 2).

Commercial production of the fiber reinforced plastic XELSC-2200 required a computer numerically controlled (CNC) machined production mold for each impeller diameter. This allowed the impeller pitch face to have complex cambered geometry; however the design of each fixed diameter XELSC-2200 impeller had to be based on the maximum torque in a pre-defined operating range. This rendered the capital cost of the XELSC-2200 impeller less competitive for the minimum torque application.

Fabricated metal impellers are made from flat stock which is available in a variety of standard thicknesses and can be readily formed using standard commercial processes. This allows the fabricated impeller to be optimally designed for the specific required torque which can, in many instances, reduce cost. The design goal was to utilize metal fabrication technology to create an impeller with a level of efficiency and anti-ragging properties that were equal to or greater than the existing Philadelphia Mixing Solutions Ltd.'s XELSC-2200 impeller. The new fabricated anti-ragging impeller design

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Nomenclature

A	angle between tangent line on blade edge projected onto horizontal plane at r_i and a radial line that passes through the impeller axis of rotation and leading edge at r_i [°]
C	blade pressure equation constant ($f(\rho$, RPM, $N_P))$
CSA	critical shedding angle [°]
D	impeller diameter [m]
E	energy efficiency (Fort)
g	gravitational constant [9.81 m/s^2]
i	array or matrix subscript
N	revolutions per minute [RPM]
OP	ARI2 roll axis angle parameter ($f(\phi1, \phi2)$) [°]
P	impeller power [W]
p	fluid pressure acting on a mixing blade at a given radial location r_i ($p = CR^2$) [Pa]
PDR	pitch-to-diameter ratio ($PDR = Pitch/D$)
PDR_{ave}	average PDR computed from the array of PDR values at each incremental blade trailing edge location r_i
$\triangle PDR$	max PDR range in array PDR_i ($\triangle PDR = \max(PDR_i) - \min(PDR_i)$)
Pitch	a constant characteristic parameter of a helix which equals the distance from any point on the helix to another similarly located point ± 180° along the helix and measured parallel to the helical axis of rotation ($Pitch = 2\pi r_i \tan(\theta_T)$) [m]
Q	impeller pumping capacity or rate [m^3/s]
R	ARI2 blade roll radius [m]
RPM	revolutions per minute
r	radial location on ARI2 blade from axis of impeller rotation [m]
T	tank diameter [m]
Q	impeller pumping capacity [m^3/s]
Z	liquid height [m]
T	tank diameter [m]
v	velocity [m/s]
x, *y*	coordinates along control volume boundary [m]

Dimensionless groups

N_P	impeller power number – $P/(\rho NpN^3D^5)$
N_Q	impeller pumping number – $Q/(ND^3)$
Fr	Froude number – N^2D/g
Re	impeller Reynolds number – $\rho ND^2/\mu$

Greek letters

α_r	rake angle of impeller
θ_T	angle of trailing edge of ARI2 blade with respect to the horizontal plane [°]
μ	fluid viscosity [kg/m/s]
μ_b	coefficient of friction between a rag fiber and a blade's leading edge
π	Pi (3.14159)
ρ	fluid density [kg/m^3]
$\phi1$	ARI2 blade roll axis orientation angle 1 [°]
$\phi2$	ARI2 blade roll axis orientation angle 2 [°]

Fig. 1 – Rag accumulation on an impeller lacking anti-rag design properties.

shall be referred to hereafter as "ARI2" (Fig. 3). The mathematical basis of the ARI2 impeller design geometry as well as its performance evaluation is included in this report.

Anoxic denitrification constitutes 75% of ARI2 applications. In anoxic denitrification, the usual solids concentration, omitting the undesired rag content, is 1000–5000 mg/l with a particle size range of 5–500 μm and a specific gravity of 1.05–1.15. The agitator's purpose is to suspend the small particles with minimal surface motion to minimize air entrainment which allows the bacteria to digest efficiently. Historical heuristic energy inputs for this gentle mixing have ranged between 3 and 8 W/m^3. Philadelphia Mixing Solutions Ltd. uses energy input (J/m^3 = Nm/m^3), rather than power input (W/m^3), to quantify the mixing requirement in the vessel to achieve the desired process result. Based on full scale process experience, the anoxic mixing may require an energy input of 0.27–1.0 J/m^3 and this may correspond to 0.92–3.3 W/m^3. Studies show excess power input to waste water bioreactors does not increase the yield and reactor success is more related to hydraulic retention time (Bridgeman, 2012; Wu, 2012). This is because reaction rates are slow relative to mixing in these applications. Therefore, the purpose of the agitator is to facilitate mass transfer so the impeller that produces the highest

Fig. 2 – Philadelphia Mixing Solution Ltd. XELSC-2200 high efficiency anti-ragging impeller developed in 2008.