KaeMix Student 2024 Verification Guide

KaeMix Documentation

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www.kaemixllc.com

support@kaemixllc.com

Summary

- This document presents comparisons between KaeMix Student predictions and literature examples for the following:
    - Power numbers
    - Blending M-Scale
    - Blend Time
    - Gas dispersion
    - Liquid dispersion
    - Solids suspension
    - Cavern size prediction
- KaeMix verification files are provided
- KaeMix Student predictions generally match the literature examples well

References

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- Hicks, Morton, Fenic (1976) *How to design agitators for desired process response*, Chemical Engineering, April issue.
- Middleton, Smith (2004) *Gas-Liquid Mixing in Turbulent Systems*, Handbook of Industrial Mixing, pp 610-613.
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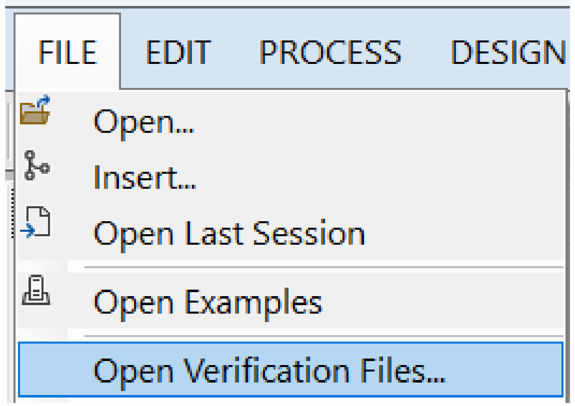
KaeMix Verification Files

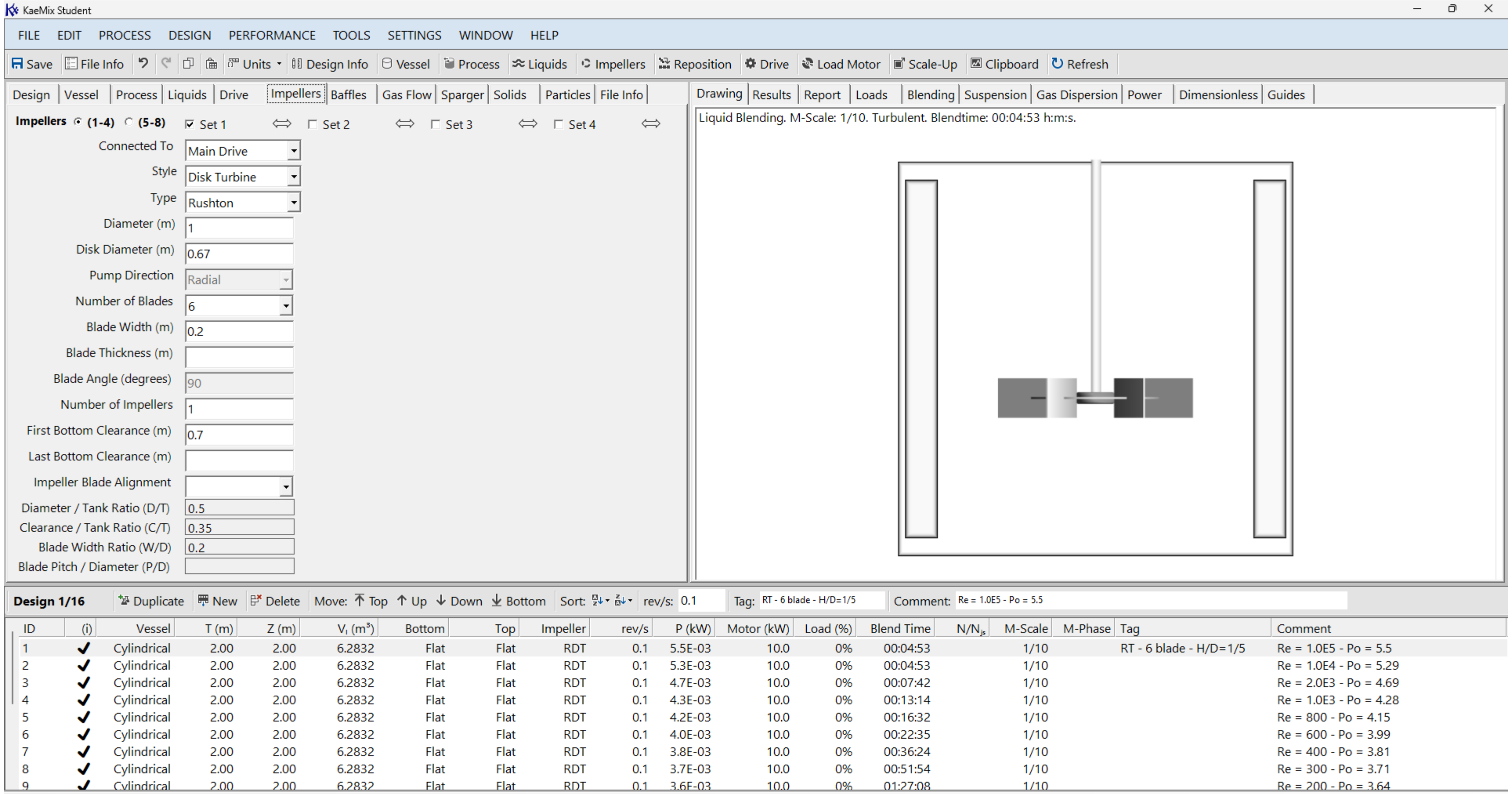


- Blending M-Scale: KM-Verify-Blending-MScale.kaemix
- Blend time: KM-Verify-BlendTime.kaemix
- Cavern size: KM-Verify-CavernSize-YieldStress-Fluid.kaemix
- Gas dispersion Pg/Pu: KM-Verify-GasDispersion-Middleton-Smith.kaemix
- Gas dispersion, flooding: KM-Verify-Gas-Flooding.kaemix
- Gas dispersion, M-Phase: KM-Verify-Gas-MPhase.kaemix
- Gas dispersion Pg/Pu: KM-Verify-Gas-Power-PgPu-Rushton-Smith.kaemix
- Po PBT: KM-Verify-Power-Number-PBT.kaemix
- Po Rushton: KM-Verify-Power-Number-Rushton.kaemix
- Po Straight Blade: KM-Verify-Power-Number-StraightBlade.kaemix
- Po Straight Blade H/D=1/8: KM-Verify-Power-Number-StraightBlade-1_8.kaemix
- Solids suspension, M-Phase: KM-Verify-MPhase-Solids.kaemix
- Solids suspension, cloud height: KM-Verify-Solids-CloudHeight-2Impellers.kaemix
- Solids, gassed suspension: KM-Verify-GassedSolids-Frijlink-Correlation.kaemix

Power Number

FILES:

- Po PBT: KM-Verify-Power-Number-PBT.kaemix
- Po Rushton: KM-Verify-Power-Number-Rushton.kaemix
- Po Straight Blade: KM-Verify-Power-Number-StraightBlade.kaemix
- Po Straight Blade H/D=1/8: KM-Verify-Power-Number-StraightBlade-1_8.kaemix



Impellers ● (1-4) ○ (5-8) ☑ Set 1 ☐ Set 2 ☐ Set 3 ☐ Set 4

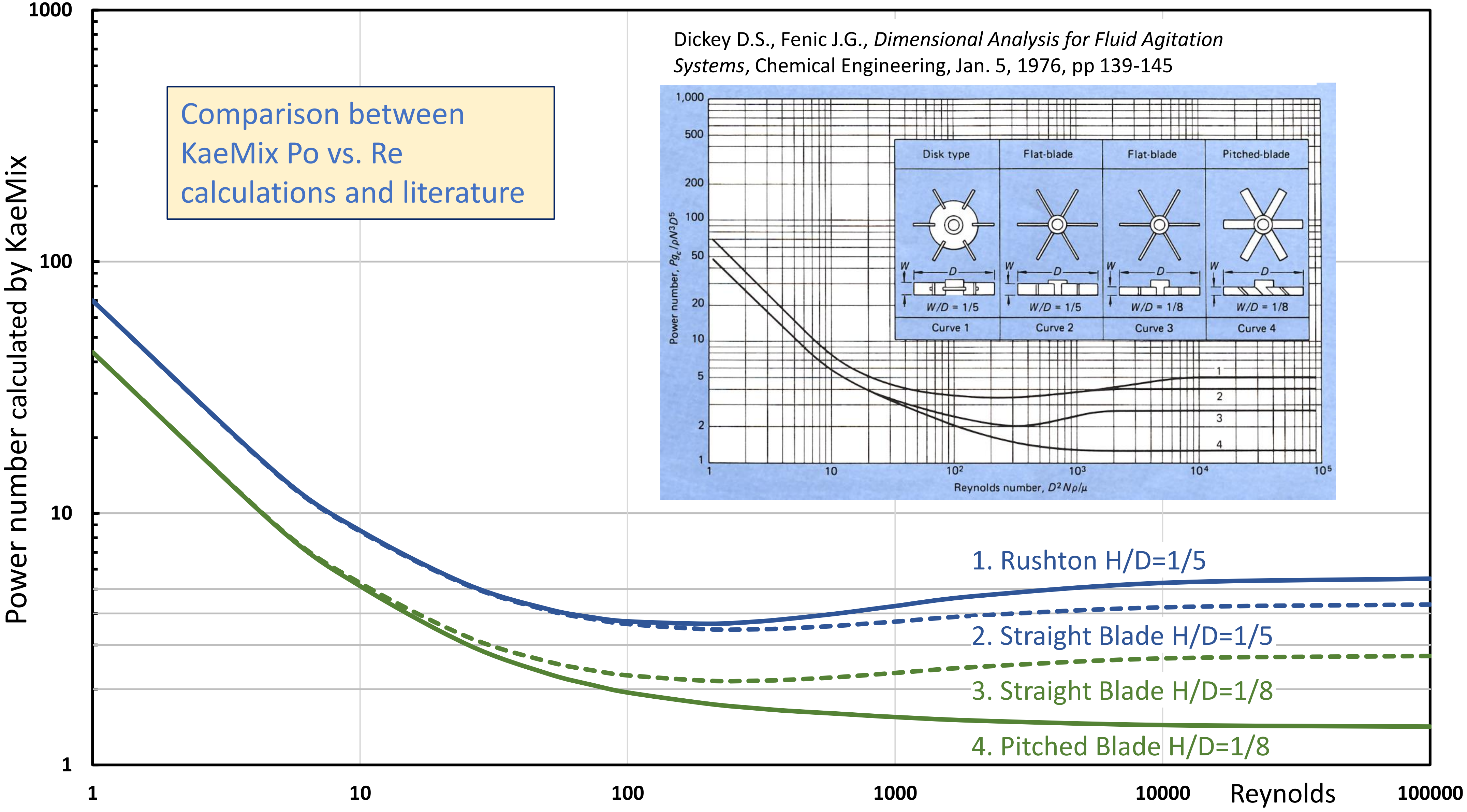
Connected To: Main Drive
Style: Disk Turbine
Type: Rushton
Diameter (m): 1
Disk Diameter (m): 0.67
Pump Direction: Radial
Number of Blades: 6
Blade Width (m): 0.2
Blade Thickness (m):
Blade Angle (degrees): 90
Number of Impellers: 1
First Bottom Clearance (m): 0.7
Last Bottom Clearance (m):
Impeller Blade Alignment:
Diameter / Tank Ratio (D/T): 0.5
Clearance / Tank Ratio (C/T): 0.35
Blade Width Ratio (W/D): 0.2
Blade Pitch / Diameter (P/D):

Liquid Blending. M-Scale: 1/10. Turbulent. Blendtime: 00:04:53 h:m:s.

Design 1/16 rev/s: 0.1 Tag: RT - 6 blade - H/D=1/5 Comment: Re = 1.0E5 - Po = 5.5

ID	(i)	Vessel	T (m)	Z (m)	V_l (m³)	Bottom	Top	Impeller	rev/s	P (kW)	Motor (kW)	Load (%)	Blend Time	N/N_{js}	M-Scale	M-Phase	Tag	Comment
1	✓	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	0.1	5.5E-03	10.0	0%	00:04:53		1/10		RT - 6 blade - H/D=1/5	Re = 1.0E5 - Po = 5.5
2	✓	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	0.1	5.3E-03	10.0	0%	00:04:53		1/10			Re = 1.0E4 - Po = 5.29
3	✓	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	0.1	4.7E-03	10.0	0%	00:07:42		1/10			Re = 2.0E3 - Po = 4.69
4	✓	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	0.1	4.3E-03	10.0	0%	00:13:14		1/10			Re = 1.0E3 - Po = 4.28
5	✓	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	0.1	4.2E-03	10.0	0%	00:16:32		1/10			Re = 800 - Po = 4.15
6	✓	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	0.1	4.0E-03	10.0	0%	00:22:35		1/10			Re = 600 - Po = 3.99
7	✓	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	0.1	3.8E-03	10.0	0%	00:36:24		1/10			Re = 400 - Po = 3.81
8	✓	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	0.1	3.7E-03	10.0	0%	00:51:54		1/10			Re = 300 - Po = 3.71
9	✓	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	0.1	3.6E-03	10.0	0%	01:27:08		1/10			Re = 200 - Po = 3.64

Power Number vs. Reynolds Number

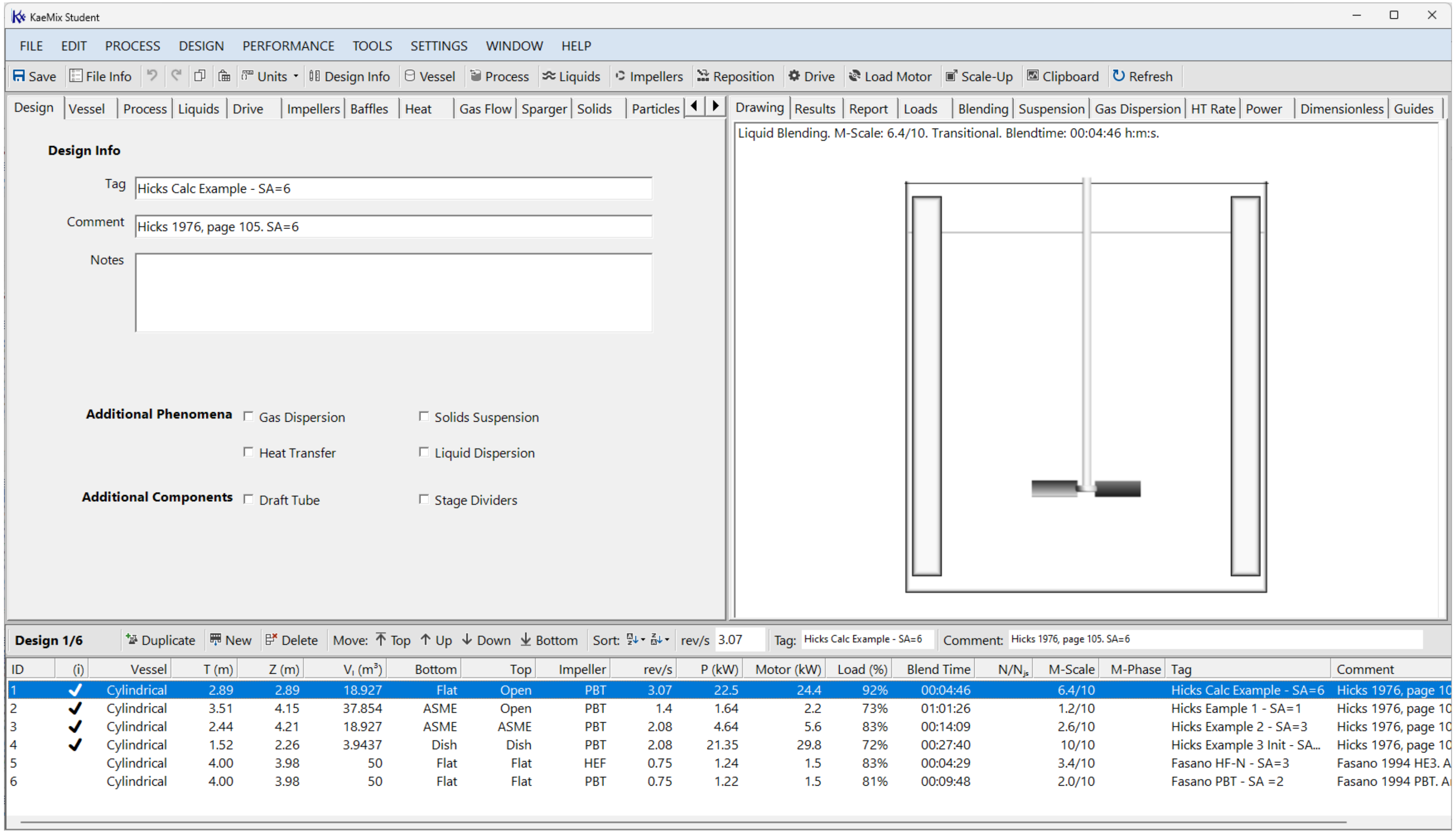


Comparison between KaeMix Po vs. Re calculations and literature

Dickey D.S., Fenic J.G., *Dimensional Analysis for Fluid Agitation Systems*, Chemical Engineering, Jan. 5, 1976, pp 139-145

Blending – M-Scale (1/4)

- File: KM-Verify-Blending-MScale.kaemix



Liquid Blending. M-Scale: 6.4/10. Transitional. Blendtime: 00:04:46 h:m:s.

Design Info

Tag: Hicks Calc Example - SA=6

Comment: Hicks 1976, page 105. SA=6

Notes:

Additional Phenomena
☐ Gas Dispersion
☐ Solids Suspension
☐ Heat Transfer
☐ Liquid Dispersion

Additional Components
☐ Draft Tube
☐ Stage Dividers

Design 1/6

rev/s: 3.07

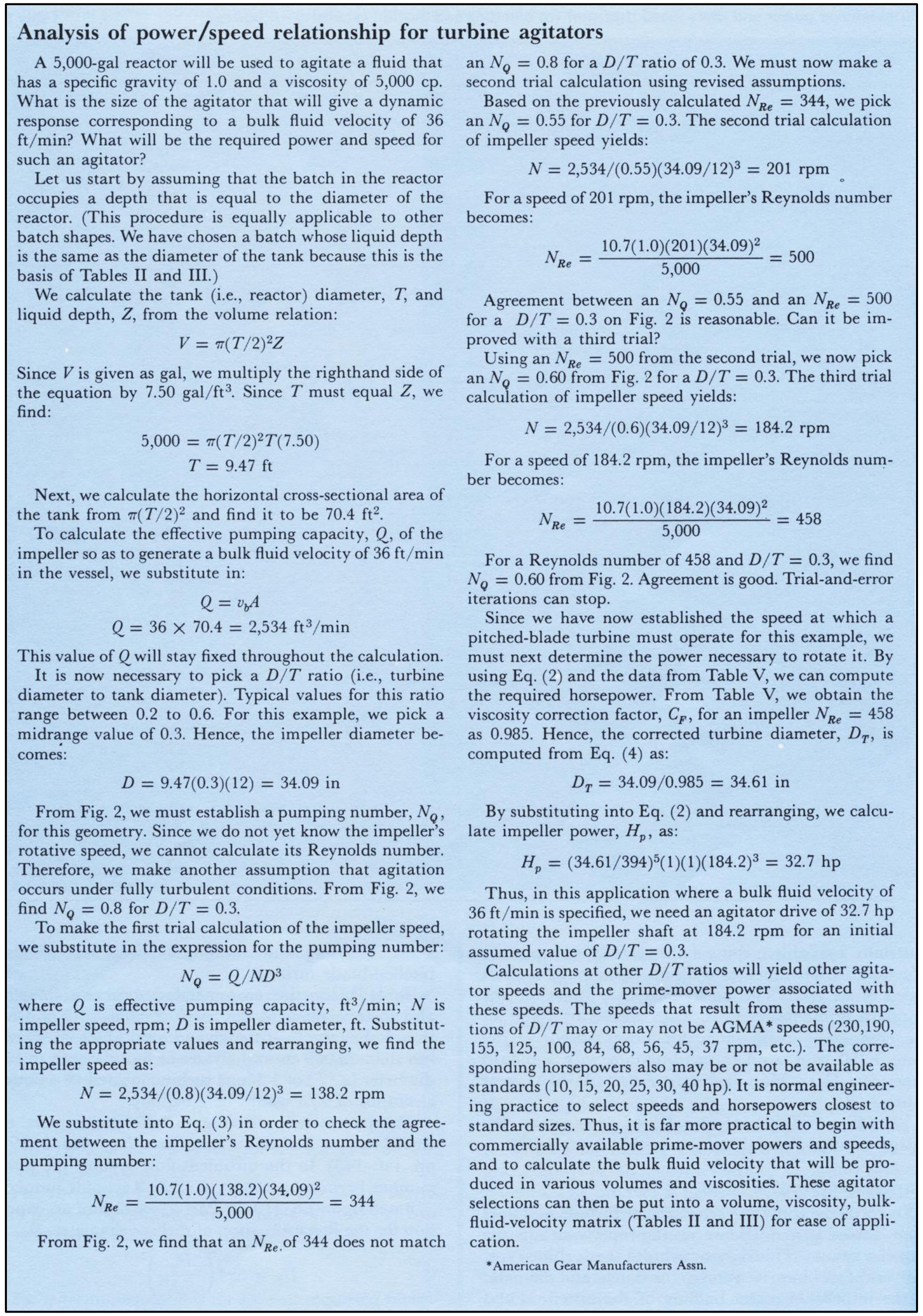
Tag: Hicks Calc Example - SA=6

Comment: Hicks 1976, page 105. SA=6

ID	(i)	Vessel	T (m)	Z (m)	V_l (m³)	Bottom	Top	Impeller	rev/s	P (kW)	Motor (kW)	Load (%)	Blend Time	N/N_{js}	M-Scale	M-Phase	Tag	Comment
1	✓	Cylindrical	2.89	2.89	18.927	Flat	Open	PBT	3.07	22.5	24.4	92%	00:04:46		6.4/10		Hicks Calc Example - SA=6	Hicks 1976, page 10
2	✓	Cylindrical	3.51	4.15	37.854	ASME	Open	PBT	1.4	1.64	2.2	73%	01:01:26		1.2/10		Hicks Eample 1 - SA=1	Hicks 1976, page 10
3	✓	Cylindrical	2.44	4.21	18.927	ASME	ASME	PBT	2.08	4.64	5.6	83%	00:14:09		2.6/10		Hicks Example 2 - SA=3	Hicks 1976, page 10
4	✓	Cylindrical	1.52	2.26	3.9437	Dish	Dish	PBT	2.08	21.35	29.8	72%	00:27:40		10/10		Hicks Example 3 Init - SA...	Hicks 1976, page 10
5		Cylindrical	4.00	3.98	50	Flat	Flat	HEF	0.75	1.24	1.5	83%	00:04:29		3.4/10		Fasano HF-N - SA=3	Fasano 1994 HE3. A
6		Cylindrical	4.00	3.98	50	Flat	Flat	PBT	0.75	1.22	1.5	81%	00:09:48		2.0/10		Fasano PBT - SA =2	Fasano 1994 PBT. A

Blending – M-Scale (2/4)

Hicks, Morton, Fenic (1976) - Example Page 125	
Volume	5000 Gallon
Specific Gravity	1
Viscosity	5000 cP
T = Z	113.7 Inch
Bottom	Flat
PBT Diameter	34.61 inch
Drive	32.7 HP
Speed	184.2 RPM
Scale of Agitation - Article	6
M-Scale - KaeMix	6.4 → Matches article



Analysis of power/speed relationship for turbine agitators

A 5,000-gal reactor will be used to agitate a fluid that has a specific gravity of 1.0 and a viscosity of 5,000 cp. What is the size of the agitator that will give a dynamic response corresponding to a bulk fluid velocity of 36 ft/min? What will be the required power and speed for such an agitator?

Let us start by assuming that the batch in the reactor occupies a depth that is equal to the diameter of the reactor. (This procedure is equally applicable to other batch shapes. We have chosen a batch whose liquid depth is the same as the diameter of the tank because this is the basis of Tables II and III.)

We calculate the tank (i.e., reactor) diameter, T, and liquid depth, Z, from the volume relation:

$$V = \pi(T/2)^2 Z$$

Since V is given as gal, we multiply the righthand side of the equation by 7.50 gal/ft^3. Since T must equal Z, we find:

$$5{,}000 = \pi(T/2)^2 T(7.50)$$
$$T = 9.47 \text{ ft}$$

Next, we calculate the horizontal cross-sectional area of the tank from $\pi(T/2)^2$ and find it to be 70.4 ft^2.

To calculate the effective pumping capacity, Q, of the impeller so as to generate a bulk fluid velocity of 36 ft/min in the vessel, we substitute in:

$$Q = v_b A$$
$$Q = 36 \times 70.4 = 2{,}534 \text{ ft}^3/\text{min}$$

This value of Q will stay fixed throughout the calculation.

It is now necessary to pick a D/T ratio (i.e., turbine diameter to tank diameter). Typical values for this ratio range between 0.2 to 0.6. For this example, we pick a midrange value of 0.3. Hence, the impeller diameter becomes:

$$D = 9.47(0.3)(12) = 34.09 \text{ in}$$

From Fig. 2, we must establish a pumping number, N_Q, for this geometry. Since we do not yet know the impeller's rotative speed, we cannot calculate its Reynolds number. Therefore, we make another assumption that agitation occurs under fully turbulent conditions. From Fig. 2, we find $N_Q = 0.8$ for $D/T = 0.3$.

To make the first trial calculation of the impeller speed, we substitute in the expression for the pumping number:

$$N_Q = Q/ND^3$$

where Q is effective pumping capacity, ft^3/min; N is impeller speed, rpm; D is impeller diameter, ft. Substituting the appropriate values and rearranging, we find the impeller speed as:

$$N = 2{,}534/(0.8)(34.09/12)^3 = 138.2 \text{ rpm}$$

We substitute into Eq. (3) in order to check the agreement between the impeller's Reynolds number and the pumping number:

$$N_{Re} = \frac{10.7(1.0)(138.2)(34.09)^2}{5{,}000} = 344$$

From Fig. 2, we find that an N_{Re} of 344 does not match an $N_Q = 0.8$ for a D/T ratio of 0.3. We must now make a second trial calculation using revised assumptions.

Based on the previously calculated $N_{Re} = 344$, we pick an $N_Q = 0.55$ for $D/T = 0.3$. The second trial calculation of impeller speed yields:

$$N = 2{,}534/(0.55)(34.09/12)^3 = 201 \text{ rpm}$$

For a speed of 201 rpm, the impeller's Reynolds number becomes:

$$N_{Re} = \frac{10.7(1.0)(201)(34.09)^2}{5{,}000} = 500$$

Agreement between an $N_Q = 0.55$ and an $N_{Re} = 500$ for a $D/T = 0.3$ on Fig. 2 is reasonable. Can it be improved with a third trial?

Using an $N_{Re} = 500$ from the second trial, we now pick an $N_Q = 0.60$ from Fig. 2 for a $D/T = 0.3$. The third trial calculation of impeller speed yields:

$$N = 2{,}534/(0.6)(34.09/12)^3 = 184.2 \text{ rpm}$$

For a speed of 184.2 rpm, the impeller's Reynolds number becomes:

$$N_{Re} = \frac{10.7(1.0)(184.2)(34.09)^2}{5{,}000} = 458$$

For a Reynolds number of 458 and $D/T = 0.3$, we find $N_Q = 0.60$ from Fig. 2. Agreement is good. Trial-and-error iterations can stop.

Since we have now established the speed at which a pitched-blade turbine must operate for this example, we must next determine the power necessary to rotate it. By using Eq. (2) and the data from Table V, we can compute the required horsepower. From Table V, we obtain the viscosity correction factor, C_F, for an impeller $N_{Re} = 458$ as 0.985. Hence, the corrected turbine diameter, D_T, is computed from Eq. (4) as:

$$D_T = 34.09/0.985 = 34.61 \text{ in}$$

By substituting into Eq. (2) and rearranging, we calculate impeller power, H_p, as:

$$H_p = (34.61/394)^5(1)(1)(184.2)^3 = 32.7 \text{ hp}$$

Thus, in this application where a bulk fluid velocity of 36 ft/min is specified, we need an agitator drive of 32.7 hp rotating the impeller shaft at 184.2 rpm for an initial assumed value of $D/T = 0.3$.

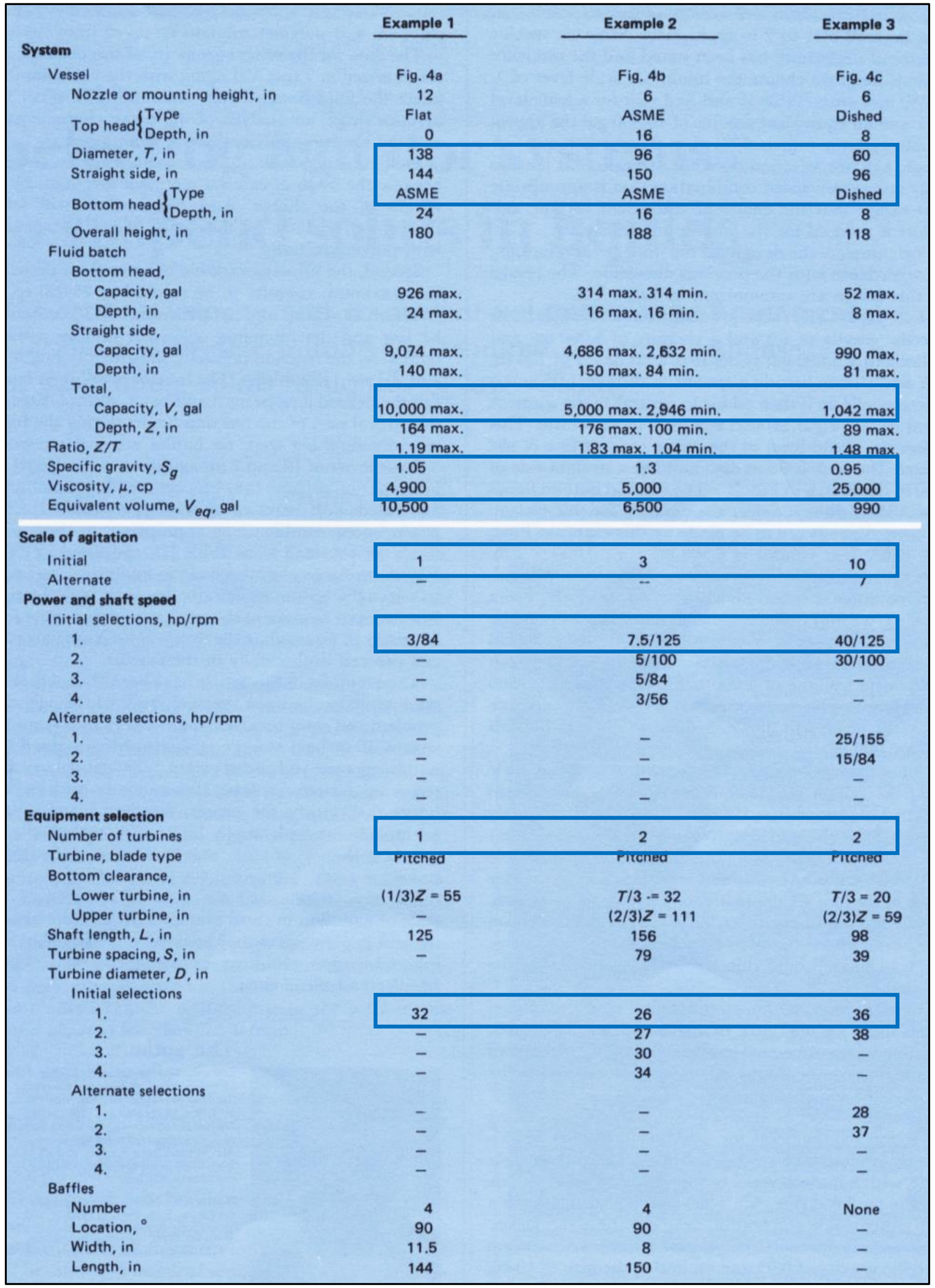
Calculations at other D/T ratios will yield other agitator speeds and the prime-mover power associated with these speeds. The speeds that result from these assumptions of D/T may or may not be AGMA* speeds (230,190, 155, 125, 100, 84, 68, 56, 45, 37 rpm, etc.). The corresponding horsepowers also may be or not be available as standards (10, 15, 20, 25, 30, 40 hp). It is normal engineering practice to select speeds and horsepowers closest to standard sizes. Thus, it is far more practical to begin with commercially available prime-mover powers and speeds, and to calculate the bulk fluid velocity that will be produced in various volumes and viscosities. These agitator selections can then be put into a volume, viscosity, bulk-fluid-velocity matrix (Tables II and III) for ease of application.

*American Gear Manufacturers Assn.

Blending – M-Scale (3/4)

Hicks, Morton, Fenic (1976) – Example Page 109

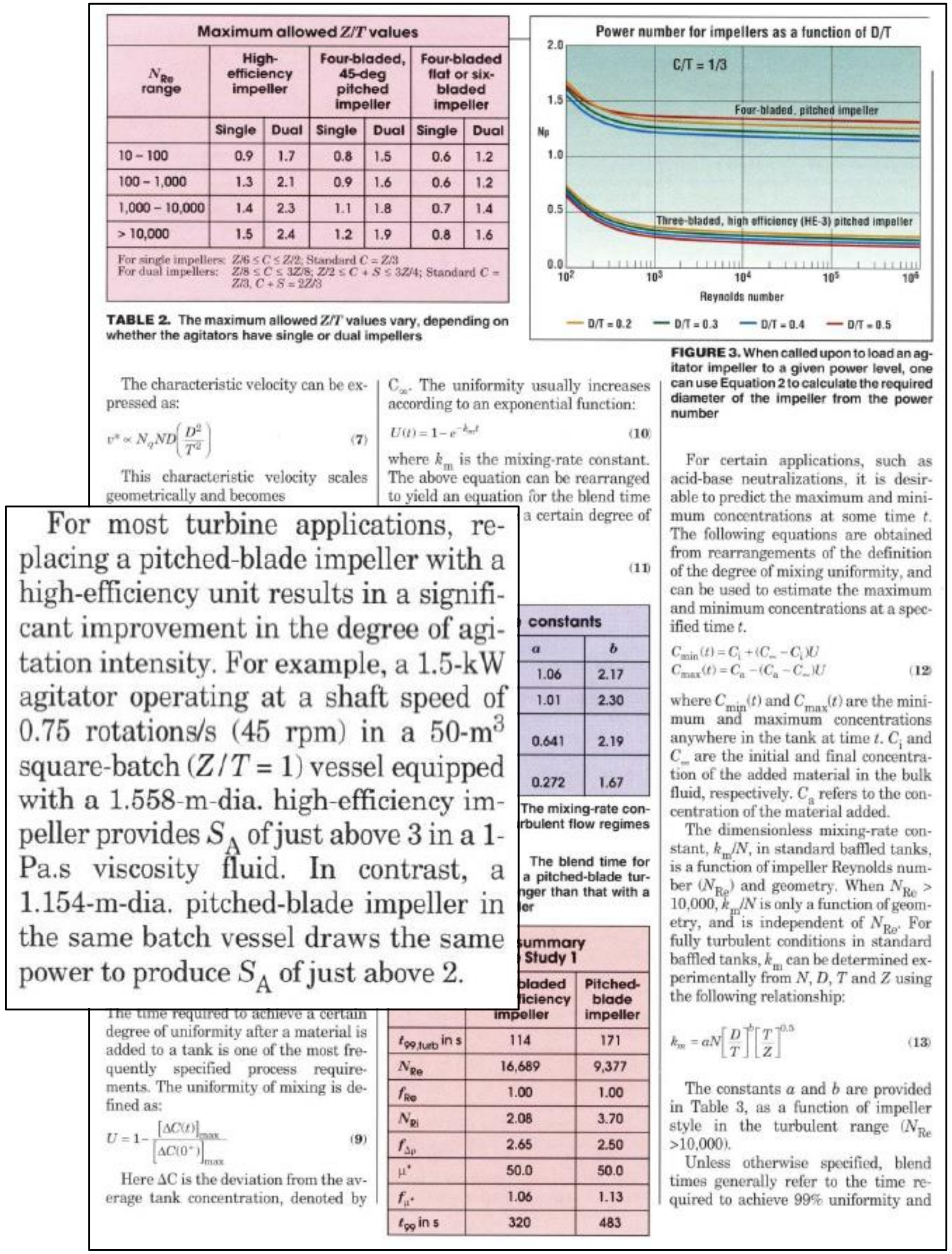
	Example 1	Example 2	Example 3
Volume	10000 Gallon	5000 Gallon	1042 Gallon
Specific Gravity	1.05	1.3	0.95
Viscosity	4900 cP	5000 cP	25000 cP
Diameter T	138 inch	96 inch	60 inch
Straight Side	144 inch	150 inch	96 inch
Bottom	ASME	ASME	Dished
Baffles	4 Standard	4 Standard	None
Number Impellers	1	2	2
PBT Diameter D	32 inch	26 inch	36 inch
Drive	3 HP	7.5 HP	40 HP
Speed	84 RPM	125 RPM	125 RPM
Scale of Agitation	1	3	10
M-Scale - KaeMix	1.2 → Matches article	2.6 → Matches article	10 → Matches article



	Example 1	Example 2	Example 3
System			
Vessel	Fig. 4a	Fig. 4b	Fig. 4c
Nozzle or mounting height, in	12	6	6
Top head Type	Flat	ASME	Dished
Top head Depth, in	0	16	8
Diameter, T, in	138	96	60
Straight side, in	144	150	96
Bottom head Type	ASME	ASME	Dished
Bottom head Depth, in	24	16	8
Overall height, in	180	188	118
Fluid batch			
Bottom head,			
Capacity, gal	926 max.	314 max. 314 min.	52 max.
Depth, in	24 max.	16 max. 16 min.	8 max.
Straight side,			
Capacity, gal	9,074 max.	4,686 max. 2,632 min.	990 max,
Depth, in	140 max.	150 max. 84 min.	81 max.
Total,			
Capacity, V, gal	10,000 max.	5,000 max. 2,946 min.	1,042 max
Depth, Z, in	164 max.	176 max. 100 min.	89 max.
Ratio, Z/T	1.19 max.	1.83 max. 1.04 min.	1.48 max.
Specific gravity, S_g	1.05	1.3	0.95
Viscosity, μ, cp	4,900	5,000	25,000
Equivalent volume, V_{eq}, gal	10,500	6,500	990
Scale of agitation			
Initial	1	3	10
Alternate	–	–	7
Power and shaft speed			
Initial selections, hp/rpm			
1.	3/84	7.5/125	40/125
2.	–	5/100	30/100
3.	–	5/84	–
4.	–	3/56	–
Alternate selections, hp/rpm			
1.	–	–	25/155
2.	–	–	15/84
3.	–	–	–
4.	–	–	–
Equipment selection			
Number of turbines	1	2	2
Turbine, blade type	Pitched	Pitched	Pitched
Bottom clearance,			
Lower turbine, in	$(1/3)Z = 55$	$T/3 = 32$	$T/3 = 20$
Upper turbine, in	–	$(2/3)Z = 111$	$(2/3)Z = 59$
Shaft length, L, in	125	156	98
Turbine spacing, S, in	–	79	39
Turbine diameter, D, in			
Initial selections			
1.	32	26	36
2.	–	27	38
3.	–	30	–
4.	–	34	–
Alternate selections			
1.	–	–	28
2.	–	–	37
3.	–	–	–
4.	–	–	–
Baffles			
Number	4	4	None
Location, °	90	90	–
Width, in	11.5	8	–
Length, in	144	150	–

Blending – M-Scale (4/4)

Fasano, Bakker, Penney (1994)		
Example	**PBT**	**High-Efficiency**
Volume	50 m^3	50 m^3
Specific Gravity	1.0	1.0
Viscosity	1000 mPa.s	1000 mPa.s
Diameter	4 m	4 m
Straight Side	4 m	4 m
Bottom	Flat	Flat
Baffles	4 Standard	4 Standard
Number Impellers	1	1
Impeller Diameter	1.154 m	1.558 m
Drive	1.5 kW	1.5 kW
Speed	45 RPM	45 RPM
Scale of Agitation Article	2	3
M-Scale - KaeMix	2.0 → Matches article	3.4 → Matches article



Maximum allowed Z/T values						
N_{Re} range	High-efficiency impeller		Four-bladed, 45-deg pitched impeller		Four-bladed flat or six-bladed impeller	
	Single	Dual	Single	Dual	Single	Dual
10 – 100	0.9	1.7	0.8	1.5	0.6	1.2
100 – 1,000	1.3	2.1	0.9	1.6	0.6	1.2
1,000 – 10,000	1.4	2.3	1.1	1.8	0.7	1.4
> 10,000	1.5	2.4	1.2	1.9	0.8	1.6

For single impellers: $Z/6 \le C \le Z/2$; Standard $C = Z/3$
For dual impellers: $Z/8 \le C \le 3Z/8$; $Z/2 \le C + S \le 3Z/4$; Standard $C = Z/3$, $C + S = 2Z/3$

TABLE 2. The maximum allowed Z/T values vary, depending on whether the agitators have single or dual impellers

FIGURE 3. When called upon to load an agitator impeller to a given power level, one can use Equation 2 to calculate the required diameter of the impeller from the power number

The characteristic velocity can be expressed as:

$$v^* \propto N_q N D\left(\frac{D^2}{T^2}\right) \quad (7)$$

This characteristic velocity scales geometrically and becomes

The time required to achieve a certain degree of uniformity after a material is added to a tank is one of the most frequently specified process requirements. The uniformity of mixing is defined as:

$$U = 1 - \frac{\left[\Delta C(t)\right]_{max}}{\left[\Delta C(0^+)\right]_{max}} \quad (9)$$

Here ΔC is the deviation from the average tank concentration, denoted by C_∞. The uniformity usually increases according to an exponential function:

$$U(t) = 1 - e^{-k_m t} \quad (10)$$

where k_m is the mixing-rate constant. The above equation can be rearranged to yield an equation for the blend time a certain degree of

(11)

constants	
a	b
1.06	2.17
1.01	2.30
0.641	2.19
0.272	1.67

The mixing-rate con- rbulent flow regimes

The blend time for a pitched-blade tur- nger than that with a ler

summary Study 1		
	bladed ficiency impeller	Pitched-blade impeller
$t_{99,turb}$ in s	114	171
N_{Re}	16,689	9,377
f_{Re}	1.00	1.00
N_{Ri}	2.08	3.70
$f_{\Delta\rho}$	2.65	2.50
μ^*	50.0	50.0
f_{μ^*}	1.06	1.13
t_{99} in s	320	483

For certain applications, such as acid-base neutralizations, it is desirable to predict the maximum and minimum concentrations at some time t. The following equations are obtained from rearrangements of the definition of the degree of mixing uniformity, and can be used to estimate the maximum and minimum concentrations at a specified time t.

$$C_{min}(t) = C_i + (C_\infty - C_i)U$$
$$C_{max}(t) = C_a - (C_a - C_\infty)U \quad (12)$$

where $C_{min}(t)$ and $C_{max}(t)$ are the minimum and maximum concentrations anywhere in the tank at time t. C_i and C_∞ are the initial and final concentration of the added material in the bulk fluid, respectively. C_a refers to the concentration of the material added.

The dimensionless mixing-rate constant, k_m/N, in standard baffled tanks, is a function of impeller Reynolds number (N_{Re}) and geometry. When N_{Re} > 10,000, k_m/N is only a function of geometry, and is independent of N_{Re}. For fully turbulent conditions in standard baffled tanks, k_m can be determined experimentally from N, D, T and Z using the following relationship:

$$k_m = aN\left[\frac{D}{T}\right]^{b}\left[\frac{T}{Z}\right]^{0.5} \quad (13)$$

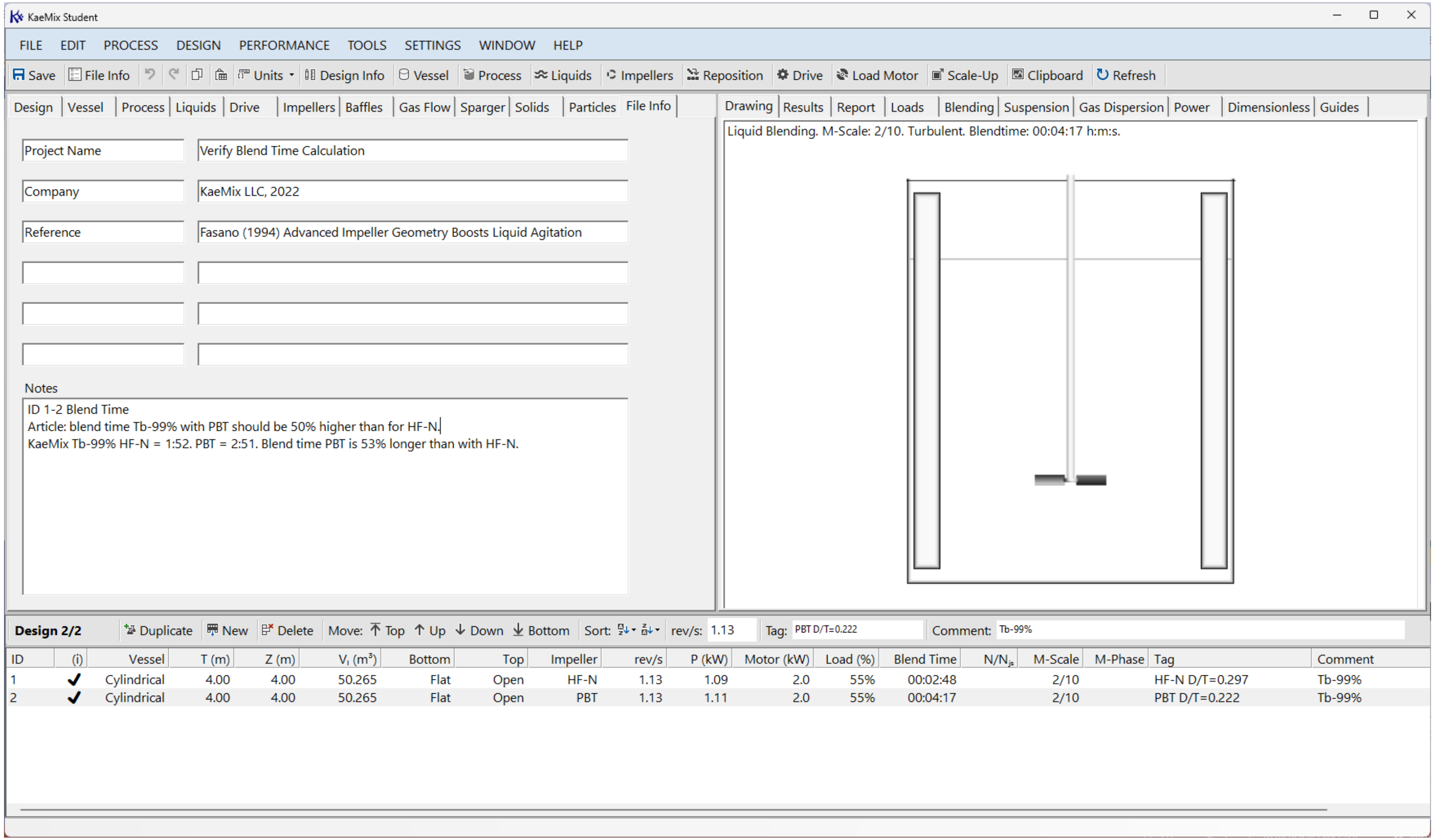
The constants a and b are provided in Table 3, as a function of impeller style in the turbulent range (N_{Re} >10,000).

Unless otherwise specified, blend times generally refer to the time required to achieve 99% uniformity and

For most turbine applications, replacing a pitched-blade impeller with a high-efficiency unit results in a significant improvement in the degree of agitation intensity. For example, a 1.5-kW agitator operating at a shaft speed of 0.75 rotations/s (45 rpm) in a 50-m^3 square-batch ($Z/T = 1$) vessel equipped with a 1.558-m-dia. high-efficiency impeller provides S_A of just above 3 in a 1-Pa.s viscosity fluid. In contrast, a 1.154-m-dia. pitched-blade impeller in the same batch vessel draws the same power to produce S_A of just above 2.

Blend Time (1/2)

- **File:** KM-Verify-BlendTime.kaemix



Project Name: Verify Blend Time Calculation

Company: KaeMix LLC, 2022

Reference: Fasano (1994) Advanced Impeller Geometry Boosts Liquid Agitation

Notes

ID 1-2 Blend Time
Article: blend time Tb-99% with PBT should be 50% higher than for HF-N.
KaeMix Tb-99% HF-N = 1:52. PBT = 2:51. Blend time PBT is 53% longer than with HF-N.

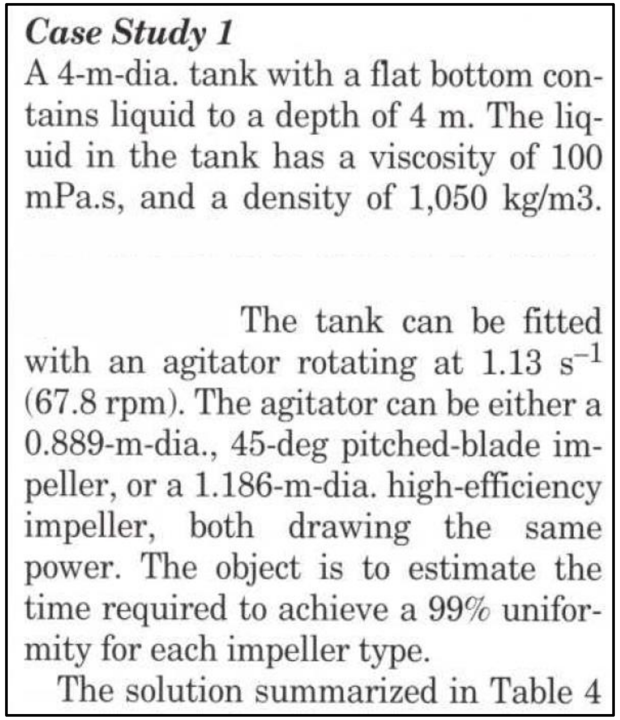
Liquid Blending. M-Scale: 2/10. Turbulent. Blendtime: 00:04:17 h:m:s.

rev/s: 1.13 Tag: PBT D/T=0.222 Comment: Tb-99%

ID	(i)	Vessel	T (m)	Z (m)	V_l (m³)	Bottom	Top	Impeller	rev/s	P (kW)	Motor (kW)	Load (%)	Blend Time	N/N_{js}	M-Scale	M-Phase	Tag	Comment
1	✓	Cylindrical	4.00	4.00	50.265	Flat	Open	HF-N	1.13	1.09	2.0	55%	00:02:48		2/10		HF-N D/T=0.297	Tb-99%
2	✓	Cylindrical	4.00	4.00	50.265	Flat	Open	PBT	1.13	1.11	2.0	55%	00:04:17		2/10		PBT D/T=0.222	Tb-99%

Blend Time (2/2)

Fasano, Bakker, Penney (1994)		
Case 1 – Blend Time	**High Efficiency**	**PBT**
Density	1050 kg/m^3	1050 kg/m^3
Viscosity	100 mPa.s	100 mPa.s
T = Z	4 m	4 m
Bottom	Flat	Flat
Baffles	4 Standard	4 Standard
Impeller Diameter	1.186 m	0.889 m
Speed	67.8 RPM	67.8 RPM
Blend Time $t_{99,\ turb}$ (Article)	00:01:54 (h:m:s) (114 s)	00:02:51 (h:m:s) (171 s)
KaeMix $t_{99,\ turb}$	00:01:53 (h:m:s)	00:02:51 (h:m:s)

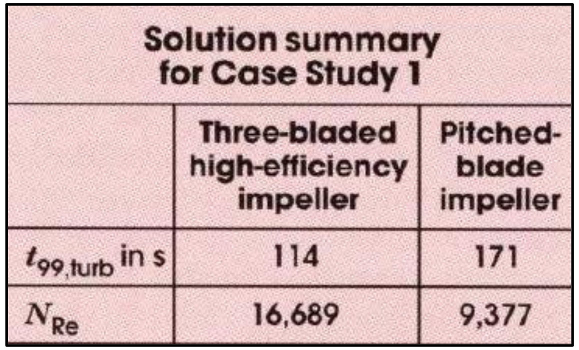


Case Study 1

A 4-m-dia. tank with a flat bottom contains liquid to a depth of 4 m. The liquid in the tank has a viscosity of 100 mPa.s, and a density of 1,050 kg/m3.

The tank can be fitted with an agitator rotating at 1.13 s^{-1} (67.8 rpm). The agitator can be either a 0.889-m-dia., 45-deg pitched-blade impeller, or a 1.186-m-dia. high-efficiency impeller, both drawing the same power. The object is to estimate the time required to achieve a 99% uniformity for each impeller type.

The solution summarized in Table 4

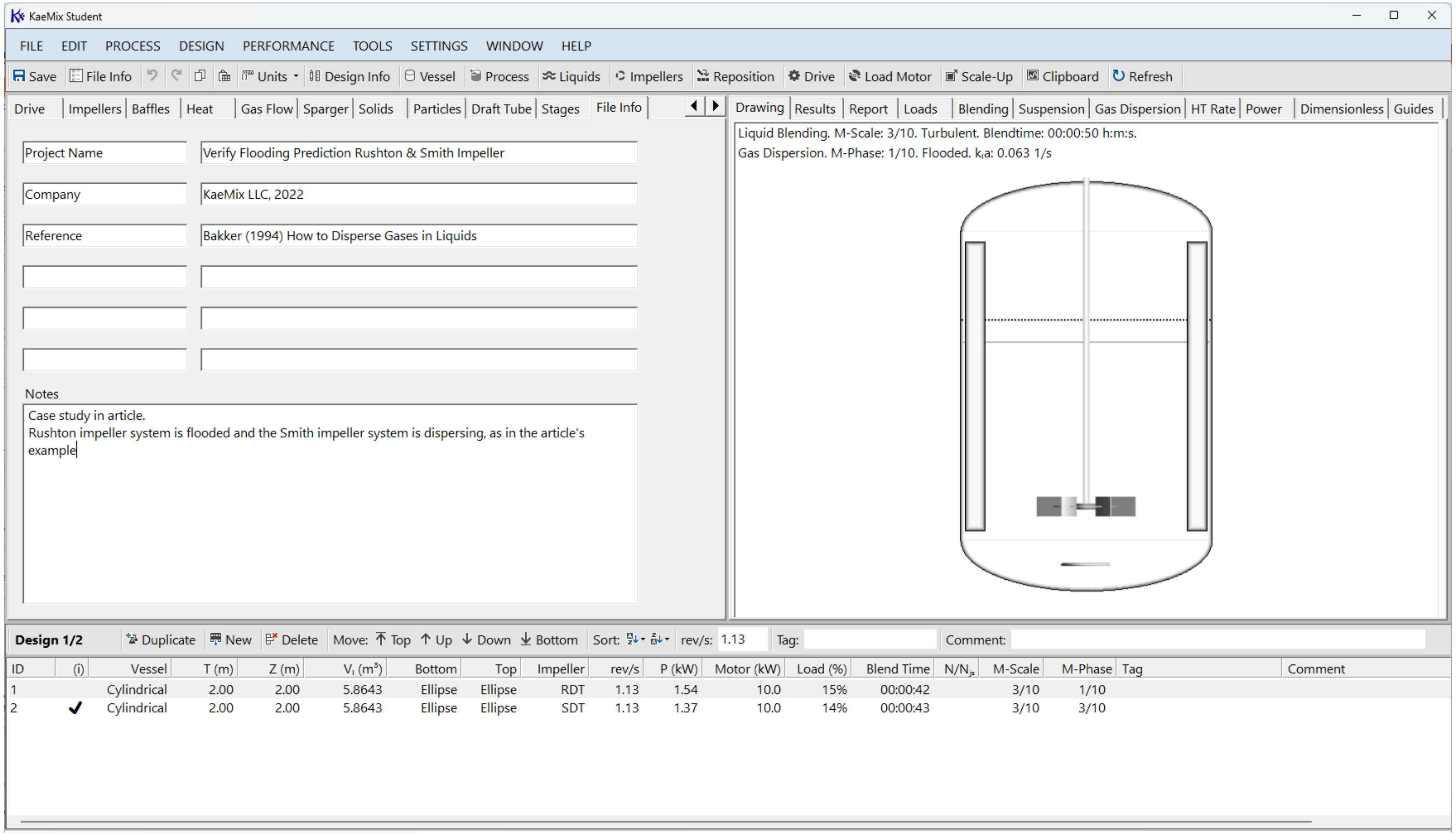


Solution summary for Case Study 1

	Three-bladed high-efficiency impeller	Pitched-blade impeller
$t_{99,turb}$ in s	114	171
N_{Re}	16,689	9,377

Gas Dispersion (1/5)

- Files: KM-Verify-Gas-Flooding.kaemix, KM-Verify-Gas-Power-PgPu-Rushton-Smith.kaemix, KM-Verify-GasDispersion-Middleton-Smith.kaemix



Project Name: Verify Flooding Prediction Rushton & Smith Impeller

Company: KaeMix LLC, 2022

Reference: Bakker (1994) How to Disperse Gases in Liquids

Notes

Case study in article.
Rushton impeller system is flooded and the Smith impeller system is dispersing, as in the article's example

Liquid Blending. M-Scale: 3/10. Turbulent. Blendtime: 00:00:50 h:m:s.
Gas Dispersion. M-Phase: 1/10. Flooded. k_la: 0.063 1/s

rev/s: 1.13

Tag:

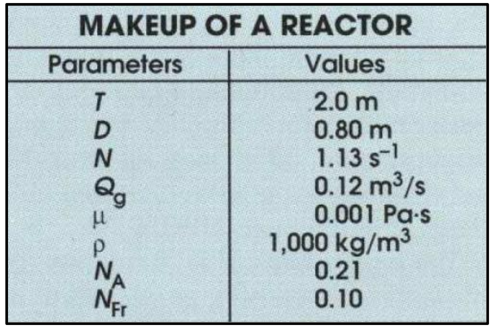
Comment:

ID	(i)	Vessel	T (m)	Z (m)	V_l (m³)	Bottom	Top	Impeller	rev/s	P (kW)	Motor (kW)	Load (%)	Blend Time	N/N_{js}	M-Scale	M-Phase	Tag	Comment
1		Cylindrical	2.00	2.00	5.8643	Ellipse	Ellipse	RDT	1.13	1.54	10.0	15%	00:00:42		3/10	1/10		
2	✓	Cylindrical	2.00	2.00	5.8643	Ellipse	Ellipse	SDT	1.13	1.37	10.0	14%	00:00:43		3/10	3/10		

Gas Dispersion (2/5)

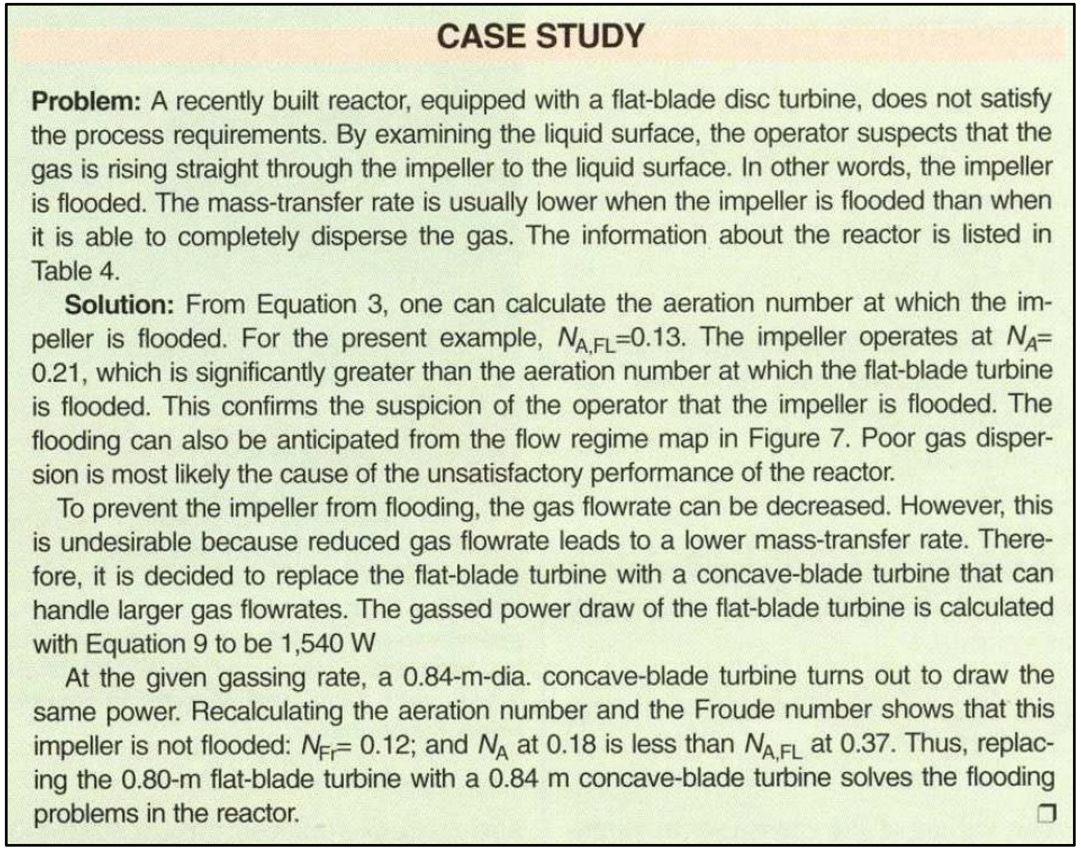
Bakker, Smith, Myers (1994)		
Impeller	**Rushton**	**Smith**
Impeller Diameter D	0.80 m	0.84 m
Speed	1.13 rev/s	1.13 rev/s
Vessel Diameter T	2.0 m	2.0 m
Viscosity	1 mPa.s	1 mPa.s
Density	1000 kg/m^3	1000 kg/m^3
Q_g	0.12 m^3/s	0.12 m^3/s
$Fl_g = N_A$	0.21	0.18
$Fr = N_{Fr}$	0.10	0.12
Article flow regime	Flooded	Dispersing
KaeMix flow regime	Flooded	Dispersing
Article Power Draw	1540 W	1540 W
KaeMix Power Draw	1538 W	1369 W*

** KaeMix uses Smith Po = 2.8 instead of 3.2 as in the article. Smith Po is D/T dependent and 3.2 is for D/T $\leq$0.25. For the intermediate to larger D/T in industrial reactors Po = 2.8 is more appropriate. This is the reason for the difference in predicted power draw*



MAKEUP OF A REACTOR

Parameters	Values
T	2.0 m
D	0.80 m
N	1.13 s^{-1}
Q_g	0.12 m^3/s
μ	0.001 Pa·s
ρ	1,000 kg/m^3
N_A	0.21
N_{Fr}	0.10



CASE STUDY

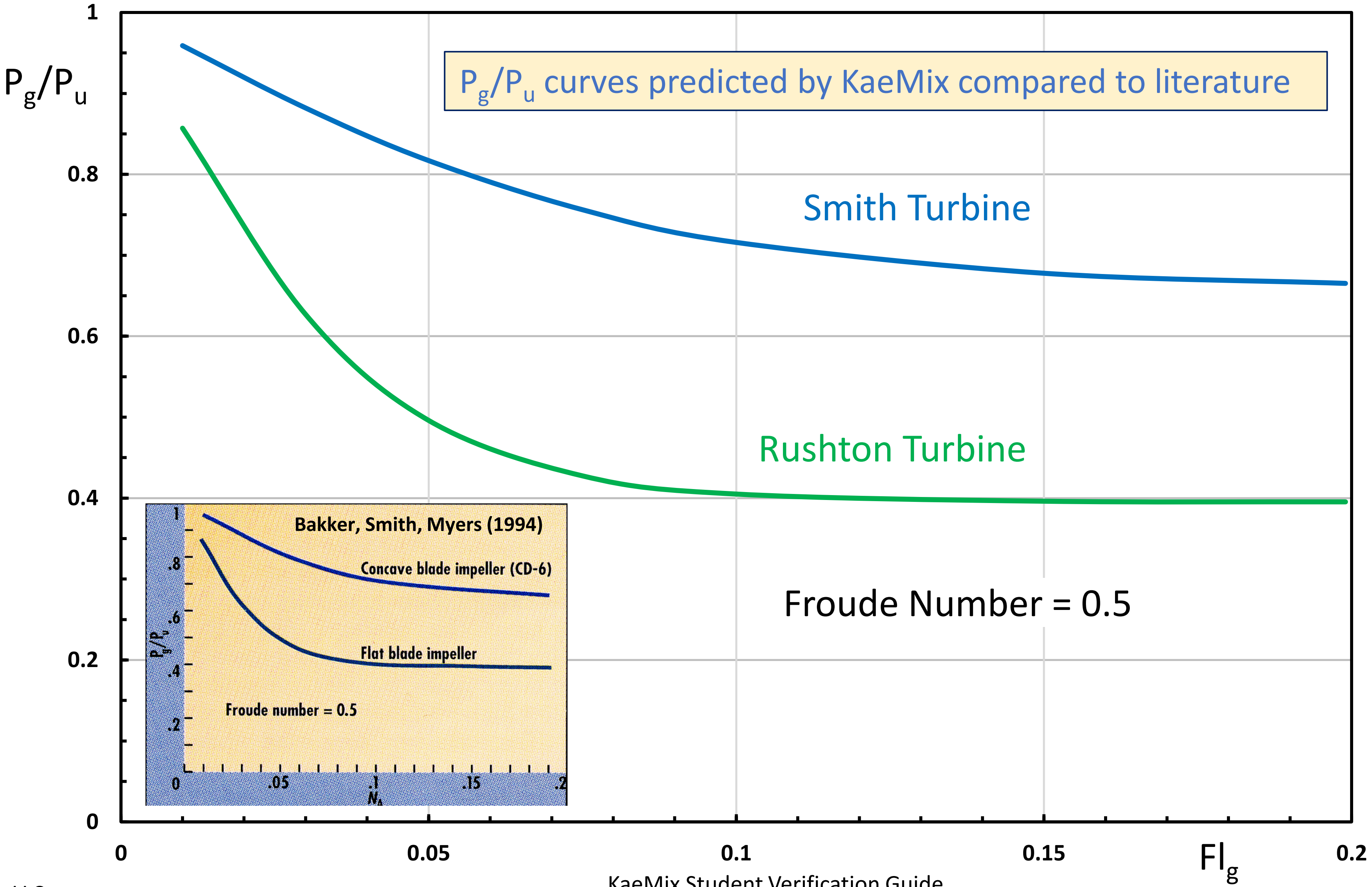
Problem: A recently built reactor, equipped with a flat-blade disc turbine, does not satisfy the process requirements. By examining the liquid surface, the operator suspects that the gas is rising straight through the impeller to the liquid surface. In other words, the impeller is flooded. The mass-transfer rate is usually lower when the impeller is flooded than when it is able to completely disperse the gas. The information about the reactor is listed in Table 4.

Solution: From Equation 3, one can calculate the aeration number at which the impeller is flooded. For the present example, $N_{A,FL}$=0.13. The impeller operates at N_A= 0.21, which is significantly greater than the aeration number at which the flat-blade turbine is flooded. This confirms the suspicion of the operator that the impeller is flooded. The flooding can also be anticipated from the flow regime map in Figure 7. Poor gas dispersion is most likely the cause of the unsatisfactory performance of the reactor.

To prevent the impeller from flooding, the gas flowrate can be decreased. However, this is undesirable because reduced gas flowrate leads to a lower mass-transfer rate. Therefore, it is decided to replace the flat-blade turbine with a concave-blade turbine that can handle larger gas flowrates. The gassed power draw of the flat-blade turbine is calculated with Equation 9 to be 1,540 W

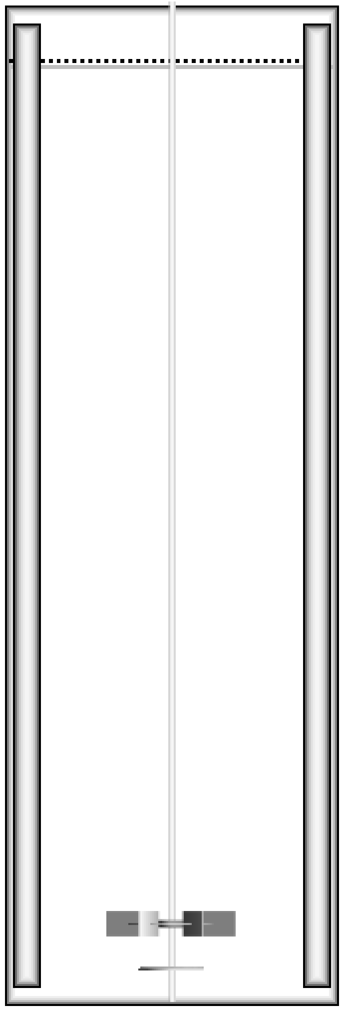
At the given gassing rate, a 0.84-m-dia. concave-blade turbine turns out to draw the same power. Recalculating the aeration number and the Froude number shows that this impeller is not flooded: N_{Fr}= 0.12; and N_A at 0.18 is less than $N_{A,FL}$ at 0.37. Thus, replacing the 0.80-m flat-blade turbine with a 0.84 m concave-blade turbine solves the flooding problems in the reactor. ❐

Gas Dispersion (3/5)

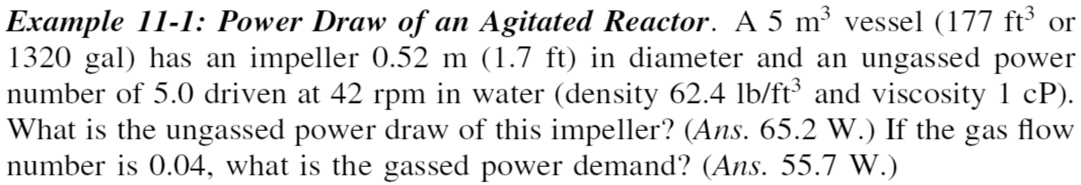


Gas Dispersion (4/5)

- Middleton and Smith, Example 11-1: *Power Draw of an Agitated Reactor*
- Filename: KM-Verify-GasDispersion-Middleton-Smith.kaemix
- KaeMix results match the Example calculations
- In order to get a Po=5 in KaeMix use a Rushton turbine with W/D=0.182
- Result for RPD = P_g/P_u:
  - Example: RPD = 0.854
  - KaeMix: P_g/P_u = 0.876 (matches well)



KaeMix Drawing



Example 11-1: Power Draw of an Agitated Reactor. A 5 m^3 vessel (177 ft^3 or 1320 gal) has an impeller 0.52 m (1.7 ft) in diameter and an ungassed power number of 5.0 driven at 42 rpm in water (density 62.4 lb/ft^3 and viscosity 1 cP). What is the ungassed power draw of this impeller? (*Ans.* 65.2 W.) If the gas flow number is 0.04, what is the gassed power demand? (*Ans.* 55.7 W.)

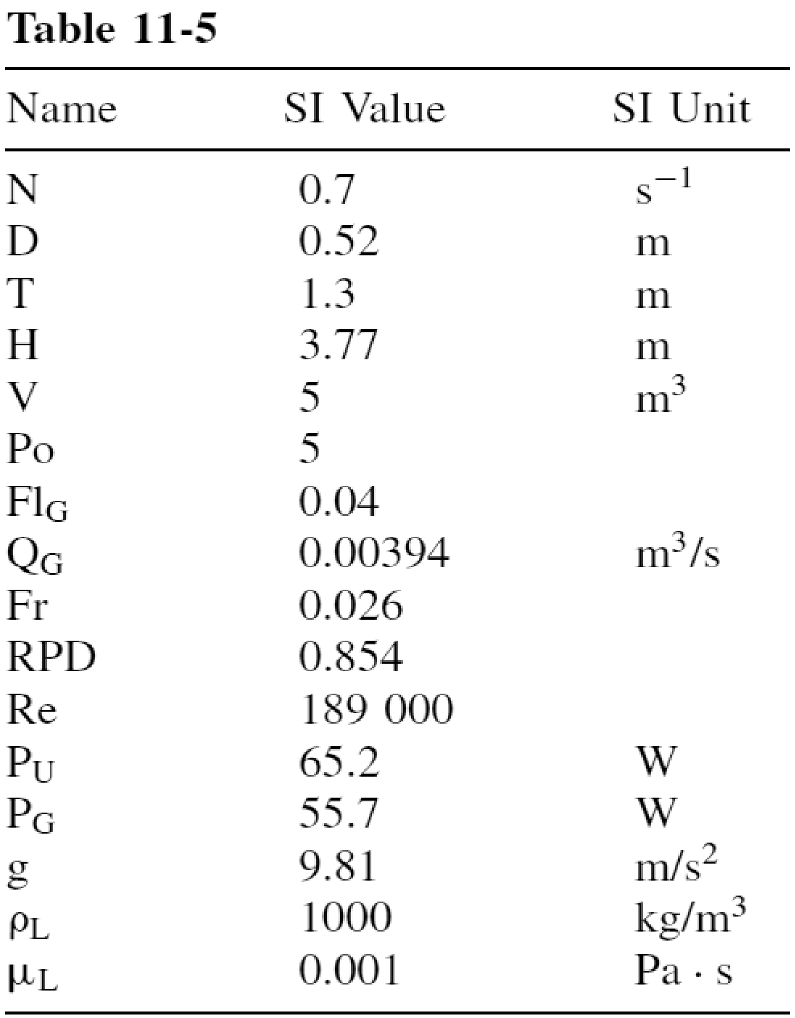
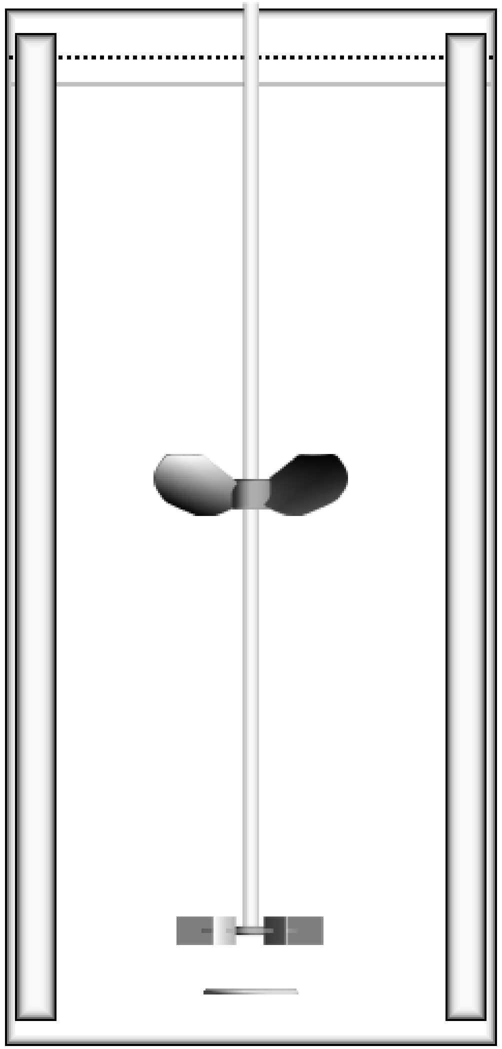


Table 11-5

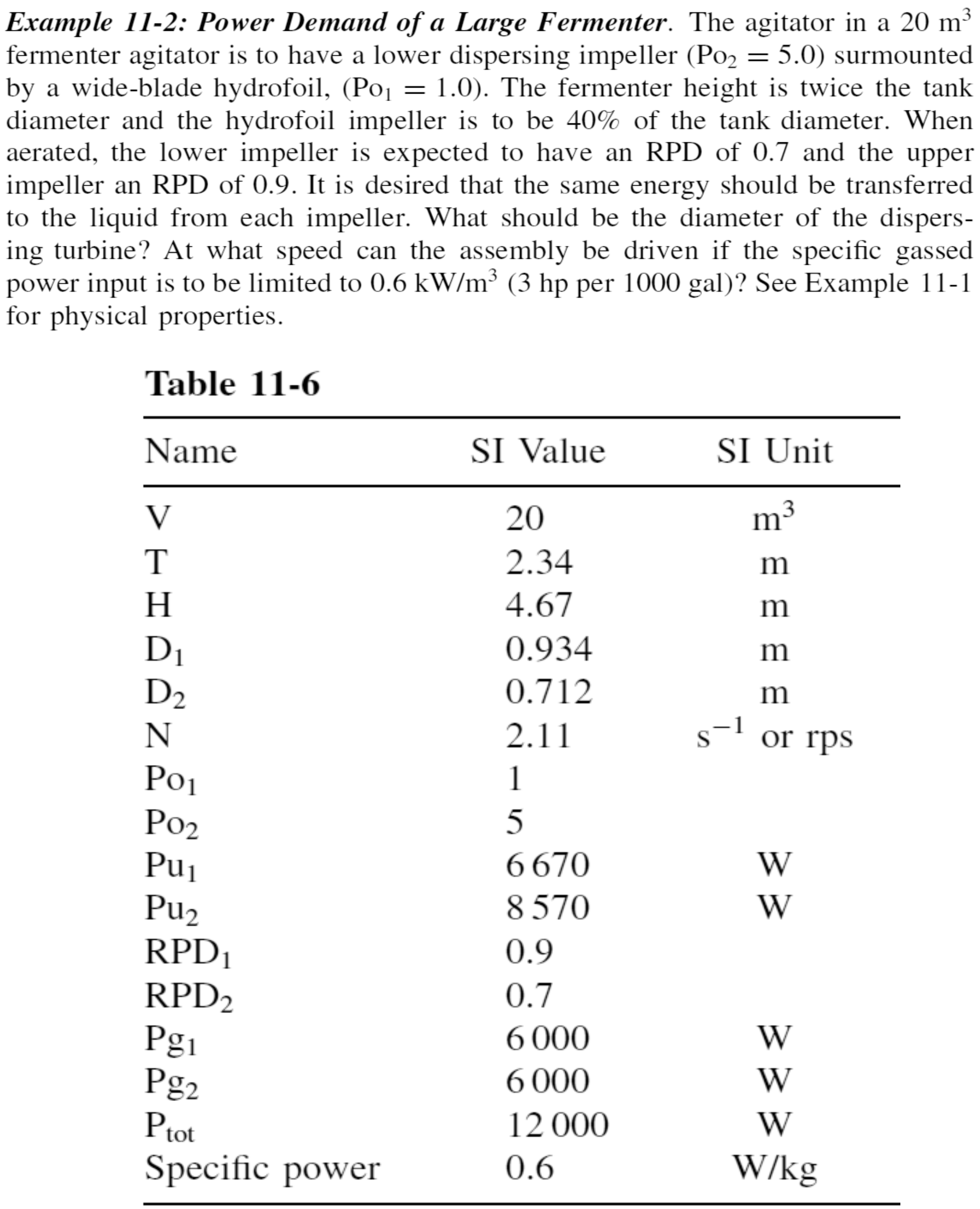
Name	SI Value	SI Unit
N	0.7	s^{-1}
D	0.52	m
T	1.3	m
H	3.77	m
V	5	m^3
Po	5	
Fl_G	0.04	
Q_G	0.00394	m^3/s
Fr	0.026	
RPD	0.854	
Re	189 000	
P_U	65.2	W
P_G	55.7	W
g	9.81	m/s^2
ρ_L	1000	kg/m^3
μ_L	0.001	$Pa \cdot s$

Gas Dispersion (5/5)

- Middleton and Smith, Example 11-2: *Power Draw of a Large Fermenter*
- Filename: KM-Verify-GasDispersion-Middleton-Smith.kaemix
- KaeMix results match the Example calculations
- In order to get a Po=5 in KaeMix use a Rushton turbine with W/D=0.182
- In order to get a Po=1 in KaeMix use HFoil-X-Wide with 4 blades
- Result for speed to get 0.6 W/kg:
  - Example: N = 2.11 rev/s
  - KaeMix: N = 2.06 rev/s (matches well)



KaeMix Drawing



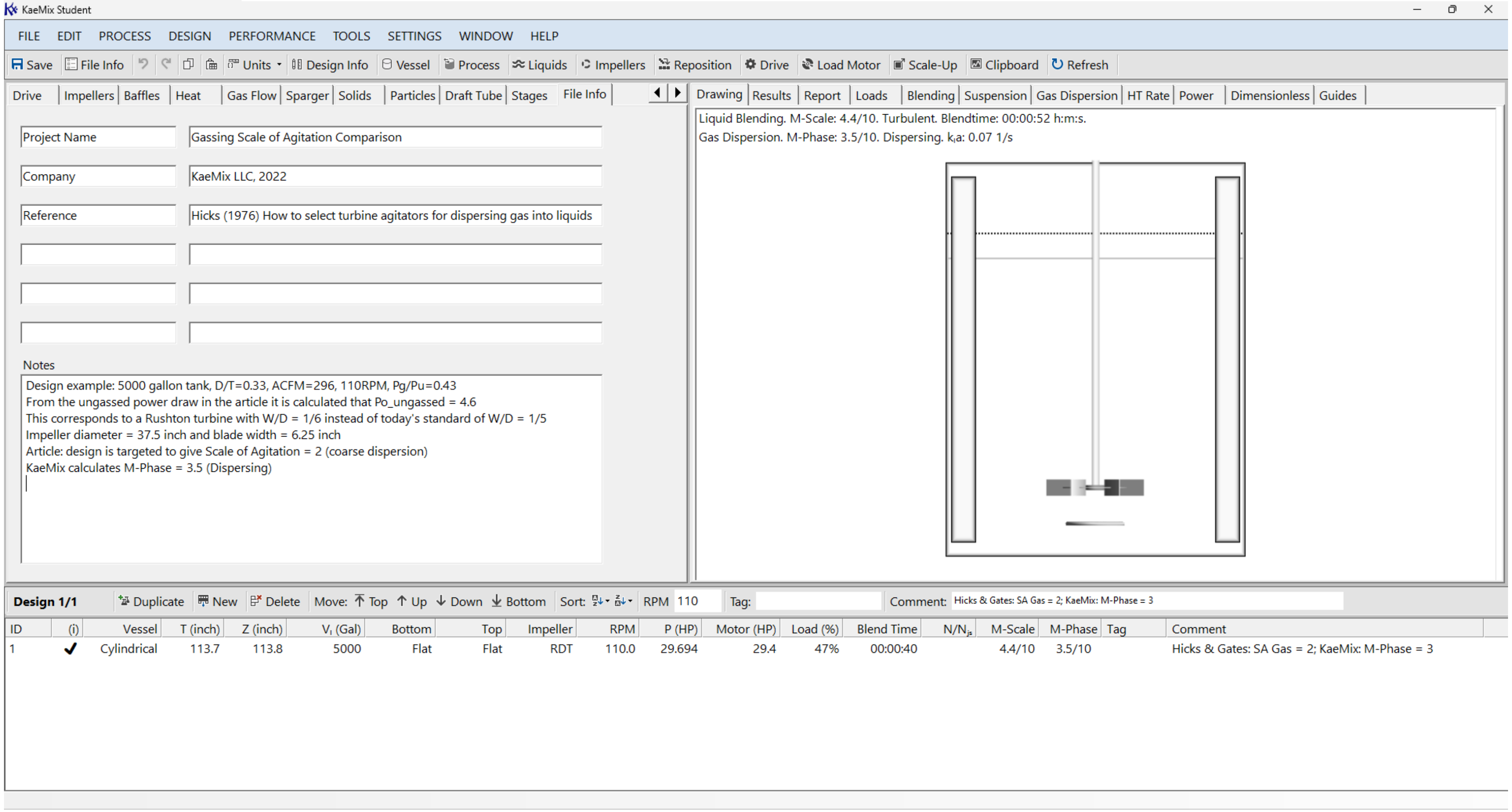
Example 11-2: Power Demand of a Large Fermenter. The agitator in a 20 m^3 fermenter agitator is to have a lower dispersing impeller ($Po_2 = 5.0$) surmounted by a wide-blade hydrofoil, ($Po_1 = 1.0$). The fermenter height is twice the tank diameter and the hydrofoil impeller is to be 40% of the tank diameter. When aerated, the lower impeller is expected to have an RPD of 0.7 and the upper impeller an RPD of 0.9. It is desired that the same energy should be transferred to the liquid from each impeller. What should be the diameter of the dispersing turbine? At what speed can the assembly be driven if the specific gassed power input is to be limited to 0.6 kW/m^3 (3 hp per 1000 gal)? See Example 11-1 for physical properties.

Table 11-6

Name	SI Value	SI Unit
V	20	m^3
T	2.34	m
H	4.67	m
D_1	0.934	m
D_2	0.712	m
N	2.11	s^{-1} or rps
Po_1	1	
Po_2	5	
Pu_1	6 670	W
Pu_2	8 570	W
RPD_1	0.9	
RPD_2	0.7	
Pg_1	6 000	W
Pg_2	6 000	W
P_{tot}	12 000	W
Specific power	0.6	W/kg

Gas Dispersion – M-Phase (1/2)

- **File:** KM-Verify-Gas-MPhase.kaemix



Project Name: Gassing Scale of Agitation Comparison

Company: KaeMix LLC, 2022

Reference: Hicks (1976) How to select turbine agitators for dispersing gas into liquids

Notes

Design example: 5000 gallon tank, D/T=0.33, ACFM=296, 110RPM, Pg/Pu=0.43
From the ungassed power draw in the article it is calculated that Po_ungassed = 4.6
This corresponds to a Rushton turbine with W/D = 1/6 instead of today's standard of W/D = 1/5
Impeller diameter = 37.5 inch and blade width = 6.25 inch
Article: design is targeted to give Scale of Agitation = 2 (coarse dispersion)
KaeMix calculates M-Phase = 3.5 (Dispersing)

Liquid Blending. M-Scale: 4.4/10. Turbulent. Blendtime: 00:00:52 h:m:s.
Gas Dispersion. M-Phase: 3.5/10. Dispersing. $k_l a$: 0.07 1/s

Design 1/1

RPM 110

Tag:

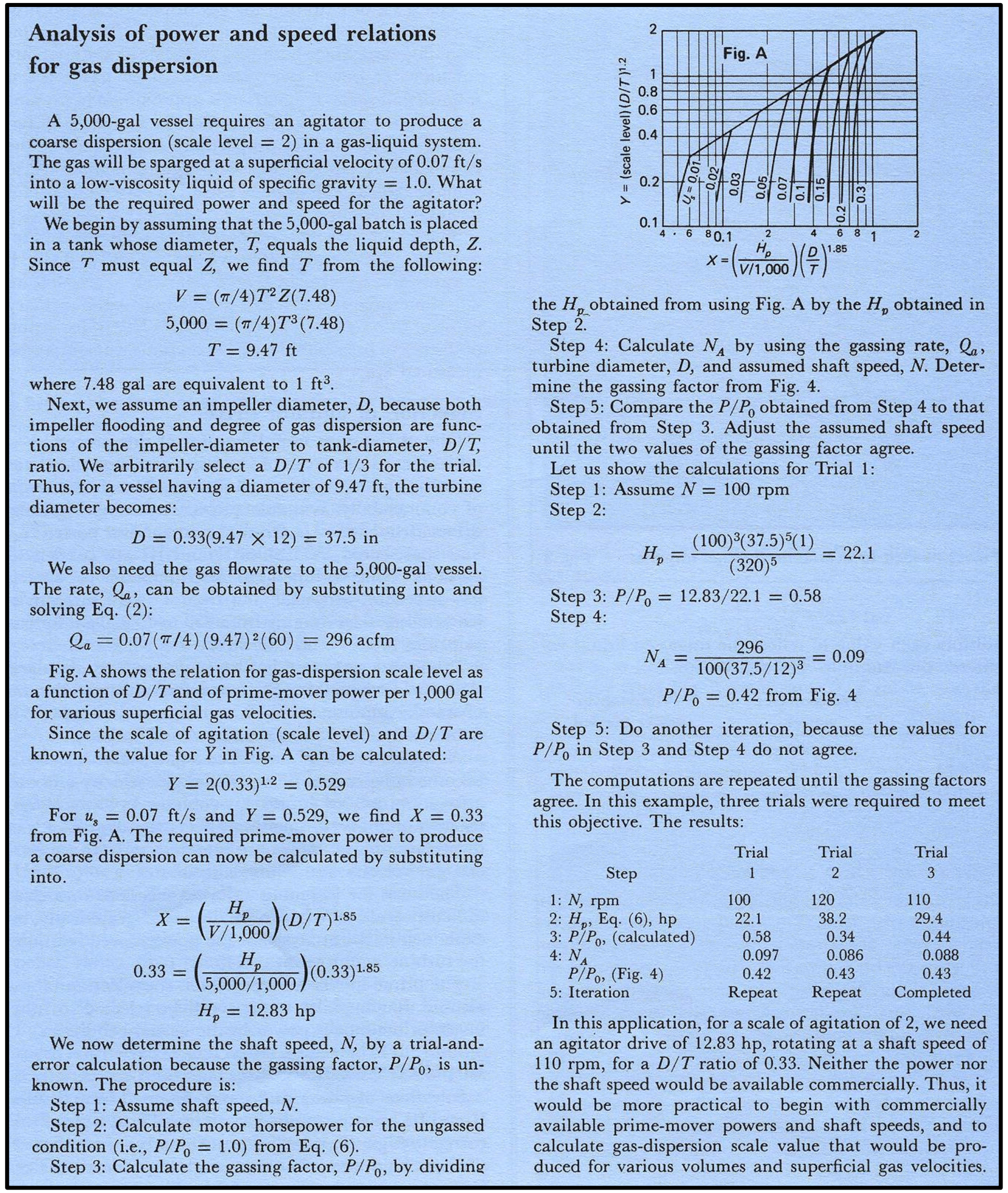
Comment: Hicks & Gates: SA Gas = 2; KaeMix: M-Phase = 3

ID	(i)	Vessel	T (inch)	Z (inch)	V_l (Gal)	Bottom	Top	Impeller	RPM	P (HP)	Motor (HP)	Load (%)	Blend Time	N/N_{js}	M-Scale	M-Phase	Tag	Comment
1	✓	Cylindrical	113.7	113.8	5000	Flat	Flat	RDT	110.0	29.694	29.4	47%	00:00:40		4.4/10	3.5/10		Hicks & Gates: SA Gas = 2; KaeMix: M-Phase = 3

Gas Dispersion – M-Phase (2/2)

Example	Hicks, Gates (1976)	KaeMix
Volume	5000 Gallon	5000 Gallon
Specific Gravity	1	1
Viscosity	1 cP	1 cP
T = Z	113.7 Inch	113.7 Inch
Bottom	Flat	Flat
Rushton Diameter	37.5 inch	37.5 inch
Blade width		6.25 inch
Speed	110 RPM	110 RPM
Gas flow rate	296 ACFM	296 ACFM
Power Draw	12.83 HP (gassed)	13.9 HP (gassed)
Ungassed Po	4.6*	4.6 (for W/D=1/6)
P_g/P_u	0.43	0.47
M-Phase	Article: 2 (Dispersing)	KaeMix: 3.5 (Dispersing)

** The article's example isn't clear on what W/D and ungassed Po are used. Calculating ungassed Po from Trial 3 info (gassed P = 12.83 HP, Pg/Pu = 0.43, RPM = 110, D = 37.5 inch, and water) results in Po = 4.6. This corresponds to a Rushton with W/D = 1/6 instead of the more common W/D = 1/5*



Analysis of power and speed relations for gas dispersion

A 5,000-gal vessel requires an agitator to produce a coarse dispersion (scale level = 2) in a gas-liquid system. The gas will be sparged at a superficial velocity of 0.07 ft/s into a low-viscosity liquid of specific gravity = 1.0. What will be the required power and speed for the agitator?

We begin by assuming that the 5,000-gal batch is placed in a tank whose diameter, T, equals the liquid depth, Z. Since T must equal Z, we find T from the following:

$$V = (\pi/4)T^2 Z(7.48)$$
$$5{,}000 = (\pi/4)T^3(7.48)$$
$$T = 9.47 \text{ ft}$$

where 7.48 gal are equivalent to 1 ft^3.

Next, we assume an impeller diameter, D, because both impeller flooding and degree of gas dispersion are functions of the impeller-diameter to tank-diameter, D/T, ratio. We arbitrarily select a D/T of 1/3 for the trial. Thus, for a vessel having a diameter of 9.47 ft, the turbine diameter becomes:

$$D = 0.33(9.47 \times 12) = 37.5 \text{ in}$$

We also need the gas flowrate to the 5,000-gal vessel. The rate, Q_a, can be obtained by substituting into and solving Eq. (2):

$$Q_a = 0.07(\pi/4)(9.47)^2(60) = 296 \text{ acfm}$$

Fig. A shows the relation for gas-dispersion scale level as a function of D/T and of prime-mover power per 1,000 gal for various superficial gas velocities.

Since the scale of agitation (scale level) and D/T are known, the value for Y in Fig. A can be calculated:

$$Y = 2(0.33)^{1.2} = 0.529$$

For $u_s = 0.07$ ft/s and $Y = 0.529$, we find $X = 0.33$ from Fig. A. The required prime-mover power to produce a coarse dispersion can now be calculated by substituting into.

$$X = \left(\frac{H_p}{V/1{,}000}\right)(D/T)^{1.85}$$
$$0.33 = \left(\frac{H_p}{5{,}000/1{,}000}\right)(0.33)^{1.85}$$
$$H_p = 12.83 \text{ hp}$$

We now determine the shaft speed, N, by a trial-and-error calculation because the gassing factor, P/P_0, is unknown. The procedure is:

Step 1: Assume shaft speed, N.

Step 2: Calculate motor horsepower for the ungassed condition (i.e., $P/P_0 = 1.0$) from Eq. (6).

Step 3: Calculate the gassing factor, P/P_0, by dividing the H_p obtained from using Fig. A by the H_p obtained in Step 2.

Step 4: Calculate N_A by using the gassing rate, Q_a, turbine diameter, D, and assumed shaft speed, N. Determine the gassing factor from Fig. 4.

Step 5: Compare the P/P_0 obtained from Step 4 to that obtained from Step 3. Adjust the assumed shaft speed until the two values of the gassing factor agree.

Let us show the calculations for Trial 1:

Step 1: Assume $N = 100$ rpm

Step 2:

$$H_p = \frac{(100)^3(37.5)^5(1)}{(320)^5} = 22.1$$

Step 3: $P/P_0 = 12.83/22.1 = 0.58$

Step 4:

$$N_A = \frac{296}{100(37.5/12)^3} = 0.09$$
$$P/P_0 = 0.42 \text{ from Fig. 4}$$

Step 5: Do another iteration, because the values for P/P_0 in Step 3 and Step 4 do not agree.

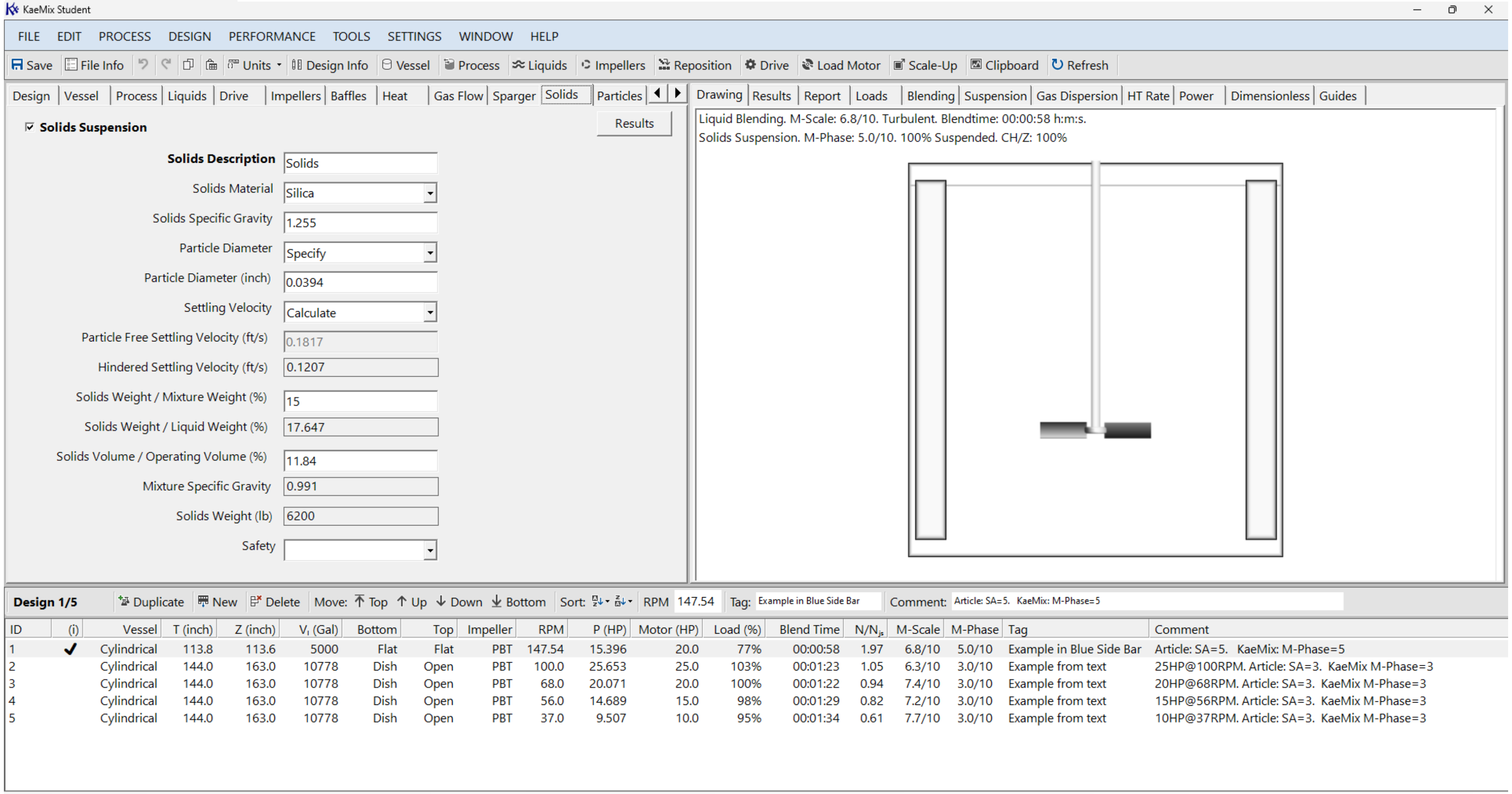
The computations are repeated until the gassing factors agree. In this example, three trials were required to meet this objective. The results:

Step	Trial 1	Trial 2	Trial 3
1: N, rpm	100	120	110
2: H_p, Eq. (6), hp	22.1	38.2	29.4
3: P/P_0, (calculated)	0.58	0.34	0.44
4: N_A	0.097	0.086	0.088
P/P_0, (Fig. 4)	0.42	0.43	0.43
5: Iteration	Repeat	Repeat	Completed

In this application, for a scale of agitation of 2, we need an agitator drive of 12.83 hp, rotating at a shaft speed of 110 rpm, for a D/T ratio of 0.33. Neither the power nor the shaft speed would be available commercially. Thus, it would be more practical to begin with commercially available prime-mover powers and shaft speeds, and to calculate gas-dispersion scale value that would be produced for various volumes and superficial gas velocities.

Solids Suspension – M-Phase (1/3)

- File: KM-Verify-MPhase-Solids.kaemix



☑ **Solids Suspension**

Solids Description Solids

Solids Material: Silica

Solids Specific Gravity: 1.255

Particle Diameter: Specify

Particle Diameter (inch): 0.0394

Settling Velocity: Calculate

Particle Free Settling Velocity (ft/s): 0.1817

Hindered Settling Velocity (ft/s): 0.1207

Solids Weight / Mixture Weight (%): 15

Solids Weight / Liquid Weight (%): 17.647

Solids Volume / Operating Volume (%): 11.84

Mixture Specific Gravity: 0.991

Solids Weight (lb): 6200

Safety:

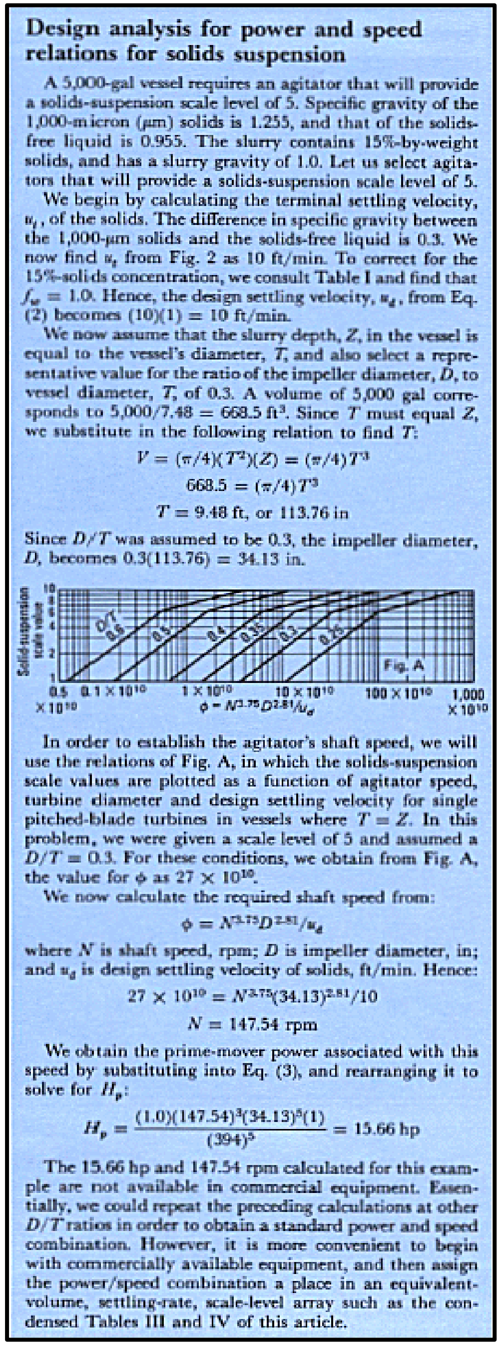
Liquid Blending. M-Scale: 6.8/10. Turbulent. Blendtime: 00:00:58 h:m:s.
Solids Suspension. M-Phase: 5.0/10. 100% Suspended. CH/Z: 100%

Design 1/5 RPM 147.54 Tag: Example in Blue Side Bar Comment: Article: SA=5. KaeMix: M-Phase=5

ID	(i)	Vessel	T (inch)	Z (inch)	V_l (Gal)	Bottom	Top	Impeller	RPM	P (HP)	Motor (HP)	Load (%)	Blend Time	N/N_{js}	M-Scale	M-Phase	Tag	Comment
1	✓	Cylindrical	113.8	113.6	5000	Flat	Flat	PBT	147.54	15.396	20.0	77%	00:00:58	1.97	6.8/10	5.0/10	Example in Blue Side Bar	Article: SA=5. KaeMix: M-Phase=5
2		Cylindrical	144.0	163.0	10778	Dish	Open	PBT	100.0	25.653	25.0	103%	00:01:23	1.05	6.3/10	3.0/10	Example from text	25HP@100RPM. Article: SA=3. KaeMix M-Phase=3
3		Cylindrical	144.0	163.0	10778	Dish	Open	PBT	68.0	20.071	20.0	100%	00:01:22	0.94	7.4/10	3.0/10	Example from text	20HP@68RPM. Article: SA=3. KaeMix M-Phase=3
4		Cylindrical	144.0	163.0	10778	Dish	Open	PBT	56.0	14.689	15.0	98%	00:01:29	0.82	7.2/10	3.0/10	Example from text	15HP@56RPM. Article: SA=3. KaeMix M-Phase=3
5		Cylindrical	144.0	163.0	10778	Dish	Open	PBT	37.0	9.507	10.0	95%	00:01:34	0.61	7.7/10	3.0/10	Example from text	10HP@37RPM. Article: SA=3. KaeMix M-Phase=3

Solids Suspension – M-Phase (2/3)

Gates, Morton, Fondy (1976)	***Design analysis for power and speed relations for solids suspension***
T = Z	113.76 inch
Volume	5000 gallons
Pitched Blade Turbine	34.13 inch; 6 blades
Speed N	147.54 RPM
Fluid	SG = 0.995; 1 mPa.s
Solids	SG = 1.255; d_p=1000μm
Solids weight fraction	15%
Settling velocity - Article	10 ft/min
Settling velocity - KaeMix	10.9 ft/min
Power draw - Article	15.66 HP
Power draw - KaeMix	15.40 HP
Scale of Agitation - Article	5
M-Phase - KaeMix	5.2 (matches article)



Design analysis for power and speed relations for solids suspension

A 5,000-gal vessel requires an agitator that will provide a solids-suspension scale level of 5. Specific gravity of the 1,000-micron (μm) solids is 1.255, and that of the solids-free liquid is 0.955. The slurry contains 15%-by-weight solids, and has a slurry gravity of 1.0. Let us select agitators that will provide a solids-suspension scale level of 5.

We begin by calculating the terminal settling velocity, u_t, of the solids. The difference in specific gravity between the 1,000-μm solids and the solids-free liquid is 0.3. We now find u_t from Fig. 2 as 10 ft/min. To correct for the 15%-solids concentration, we consult Table I and find that f_w = 1.0. Hence, the design settling velocity, u_d, from Eq. (2) becomes (10)(1) = 10 ft/min.

We now assume that the slurry depth, Z, in the vessel is equal to the vessel's diameter, T, and also select a representative value for the ratio of the impeller diameter, D, to vessel diameter, T, of 0.3. A volume of 5,000 gal corresponds to 5,000/7.48 = 668.5 ft³. Since T must equal Z, we substitute in the following relation to find T:

$$V = (\pi/4)(T^2)(Z) = (\pi/4)T^3$$

$$668.5 = (\pi/4)T^3$$

$$T = 9.48 \text{ ft, or } 113.76 \text{ in}$$

Since D/T was assumed to be 0.3, the impeller diameter, D, becomes 0.3(113.76) = 34.13 in.

In order to establish the agitator's shaft speed, we will use the relations of Fig. A, in which the solids-suspension scale values are plotted as a function of agitator speed, turbine diameter and design settling velocity for single pitched-blade turbines in vessels where $T = Z$. In this problem, we were given a scale level of 5 and assumed a D/T = 0.3. For these conditions, we obtain from Fig. A, the value for ϕ as 27×10^{10}.

We now calculate the required shaft speed from:

$$\phi = N^{2.75}D^{2.81}/u_d$$

where N is shaft speed, rpm; D is impeller diameter, in; and u_d is design settling velocity of solids, ft/min. Hence:

$$27 \times 10^{10} = N^{2.75}(34.13)^{2.81}/10$$

$$N = 147.54 \text{ rpm}$$

We obtain the prime-mover power associated with this speed by substituting into Eq. (3), and rearranging it to solve for H_p:

$$H_p = \frac{(1.0)(147.54)^3(34.13)^5(1)}{(394)^5} = 15.66 \text{ hp}$$

The 15.66 hp and 147.54 rpm calculated for this example are not available in commercial equipment. Essentially, we could repeat the preceding calculations at other D/T ratios in order to obtain a standard power and speed combination. However, it is more convenient to begin with commercially available equipment, and then assign the power/speed combination a place in an equivalent-volume, settling-rate, scale-level array such as the condensed Tables III and IV of this article.

Solids Suspension – M-Phase (3/3)

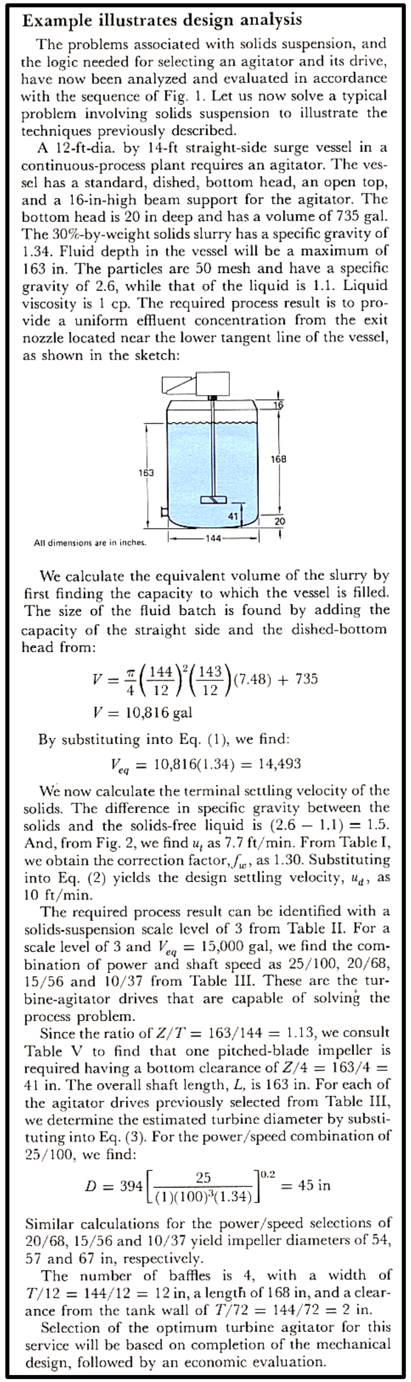
Gates, Morton, Fondy (1976)	*Example illustrates design analysis*
T = 144 inch	Z = 163 inch
Volume	~10800 gallons
Pitched Blade Turbine	6 blades; C = 41 inch
Fluid	SG = 1.1; 1 mPa.s
Solids	SG = 2.6; 50 mesh = 310μm
Solids weight fraction	30%

Design 1: 25 HP at 100 RPM. Impeller D = 45 inch	
Scale of Agitation - Article	3
M-Phase - KaeMix	3.5 (matches article)

Design 2: 20 HP at 68 RPM. Impeller D = 54 inch	
Scale of Agitation – Article	3
M-Phase - KaeMix	3 (matches article)

Design 3: 15 HP at 56 RPM. Impeller D = 57 inch	
Scale of Agitation - Article	3
M-Phase - KaeMix	3 (matches article)

Design 4: 10 HP at 37 RPM. Impeller D = 67 inch	
Scale of Agitation - Article	3
M-Phase - KaeMix	2.5 (matches article)



Example illustrates design analysis

The problems associated with solids suspension, and the logic needed for selecting an agitator and its drive, have now been analyzed and evaluated in accordance with the sequence of Fig. 1. Let us now solve a typical problem involving solids suspension to illustrate the techniques previously described.

A 12-ft-dia. by 14-ft straight-side surge vessel in a continuous-process plant requires an agitator. The vessel has a standard, dished, bottom head, an open top, and a 16-in-high beam support for the agitator. The bottom head is 20 in deep and has a volume of 735 gal. The 30%-by-weight solids slurry has a specific gravity of 1.34. Fluid depth in the vessel will be a maximum of 163 in. The particles are 50 mesh and have a specific gravity of 2.6, while that of the liquid is 1.1. Liquid viscosity is 1 cp. The required process result is to provide a uniform effluent concentration from the exit nozzle located near the lower tangent line of the vessel, as shown in the sketch:

All dimensions are in inches.

We calculate the equivalent volume of the slurry by first finding the capacity to which the vessel is filled. The size of the fluid batch is found by adding the capacity of the straight side and the dished-bottom head from:

$$V = \frac{\pi}{4}\left(\frac{144}{12}\right)^2\left(\frac{143}{12}\right)(7.48) + 735$$

$$V = 10{,}816 \text{ gal}$$

By substituting into Eq. (1), we find:

$$V_{eq} = 10{,}816(1.34) = 14{,}493$$

We now calculate the terminal settling velocity of the solids. The difference in specific gravity between the solids and the solids-free liquid is $(2.6 - 1.1) = 1.5$. And, from Fig. 2, we find u_t as 7.7 ft/min. From Table I, we obtain the correction factor, f_w, as 1.30. Substituting into Eq. (2) yields the design settling velocity, u_d, as 10 ft/min.

The required process result can be identified with a solids-suspension scale level of 3 from Table II. For a scale level of 3 and $V_{eq} = 15{,}000$ gal, we find the combination of power and shaft speed as 25/100, 20/68, 15/56 and 10/37 from Table III. These are the turbine-agitator drives that are capable of solving the process problem.

Since the ratio of $Z/T = 163/144 = 1.13$, we consult Table V to find that one pitched-blade impeller is required having a bottom clearance of $Z/4 = 163/4 = 41$ in. The overall shaft length, L, is 163 in. For each of the agitator drives previously selected from Table III, we determine the estimated turbine diameter by substituting into Eq. (3). For the power/speed combination of 25/100, we find:

$$D = 394\left[\frac{25}{(1)(100)^3(1.34)}\right]^{0.2} = 45 \text{ in}$$

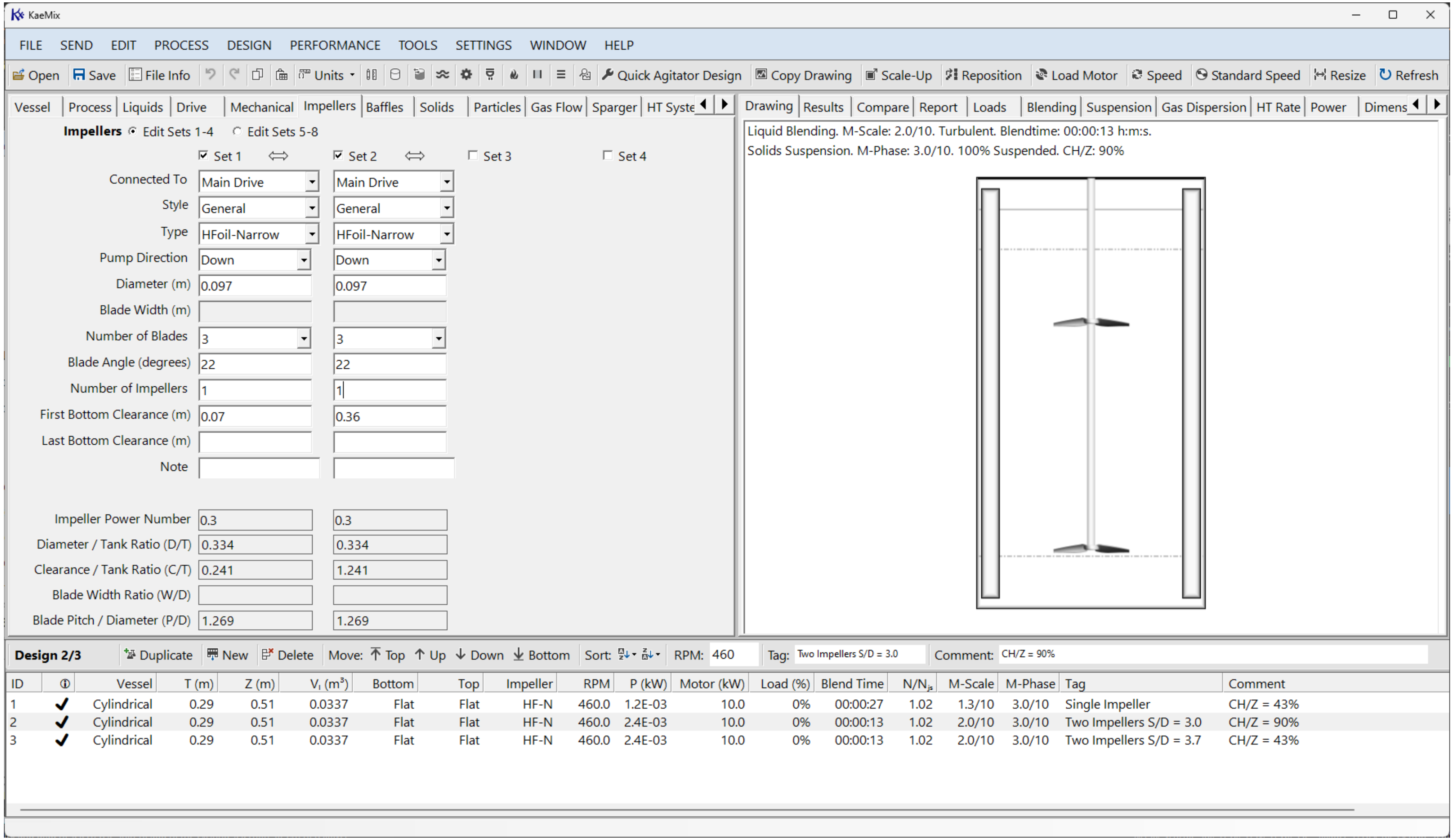
Similar calculations for the power/speed selections of 20/68, 15/56 and 10/37 yield impeller diameters of 54, 57 and 67 in, respectively.

The number of baffles is 4, with a width of $T/12 = 144/12 = 12$ in, a length of 168 in, and a clearance from the tank wall of $T/72 = 144/72 = 2$ in.

Selection of the optimum turbine agitator for this service will be based on completion of the mechanical design, followed by an economic evaluation.

Solids Cloud Height (1/2)

- **File:** KM-Verify-Solids-CloudHeight-2Impellers.kaemix



Impellers ● Edit Sets 1-4 ○ Edit Sets 5-8

	☑ Set 1	☑ Set 2	☐ Set 3	☐ Set 4
Connected To	Main Drive	Main Drive		
Style	General	General		
Type	HFoil-Narrow	HFoil-Narrow		
Pump Direction	Down	Down		
Diameter (m)	0.097	0.097		
Blade Width (m)				
Number of Blades	3	3		
Blade Angle (degrees)	22	22		
Number of Impellers	1	1		
First Bottom Clearance (m)	0.07	0.36		
Last Bottom Clearance (m)				
Note				
Impeller Power Number	0.3	0.3		
Diameter / Tank Ratio (D/T)	0.334	0.334		
Clearance / Tank Ratio (C/T)	0.241	1.241		
Blade Width Ratio (W/D)				
Blade Pitch / Diameter (P/D)	1.269	1.269		

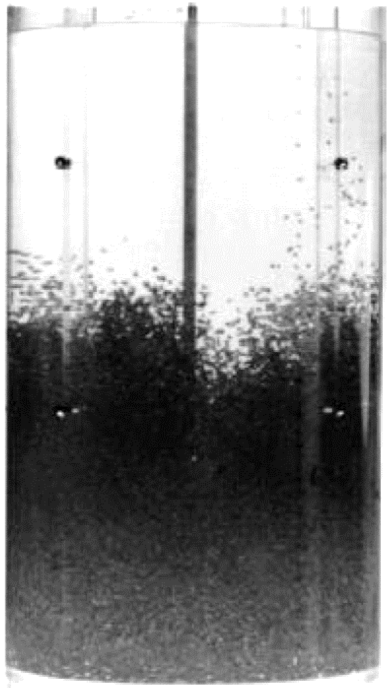
Liquid Blending. M-Scale: 2.0/10. Turbulent. Blendtime: 00:00:13 h:m:s.

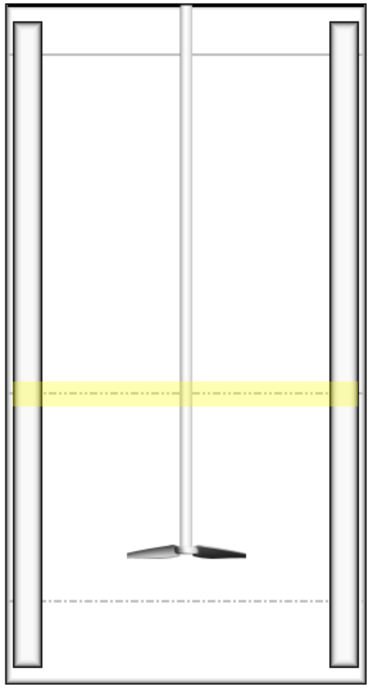
Solids Suspension. M-Phase: 3.0/10. 100% Suspended. CH/Z: 90%

Design 2/3 RPM: 460 Tag: Two Impellers S/D = 3.0 Comment: CH/Z = 90%

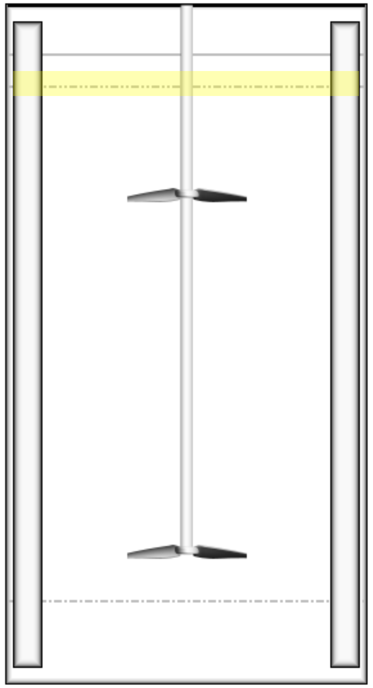
ID	①	Vessel	T (m)	Z (m)	V_l (m³)	Bottom	Top	Impeller	RPM	P (kW)	Motor (kW)	Load (%)	Blend Time	N/N_{js}	M-Scale	M-Phase	Tag	Comment
1	✓	Cylindrical	0.29	0.51	0.0337	Flat	Flat	HF-N	460.0	1.2E-03	10.0	0%	00:00:27	1.02	1.3/10	3.0/10	Single Impeller	CH/Z = 43%
2	✓	Cylindrical	0.29	0.51	0.0337	Flat	Flat	HF-N	460.0	2.4E-03	10.0	0%	00:00:13	1.02	2.0/10	3.0/10	Two Impellers S/D = 3.0	CH/Z = 90%
3	✓	Cylindrical	0.29	0.51	0.0337	Flat	Flat	HF-N	460.0	2.4E-03	10.0	0%	00:00:13	1.02	2.0/10	3.0/10	Two Impellers S/D = 3.7	CH/Z = 43%

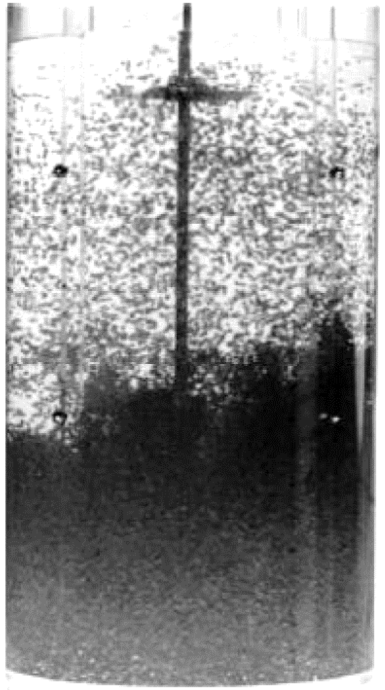
Solids Cloud Height (2/2)

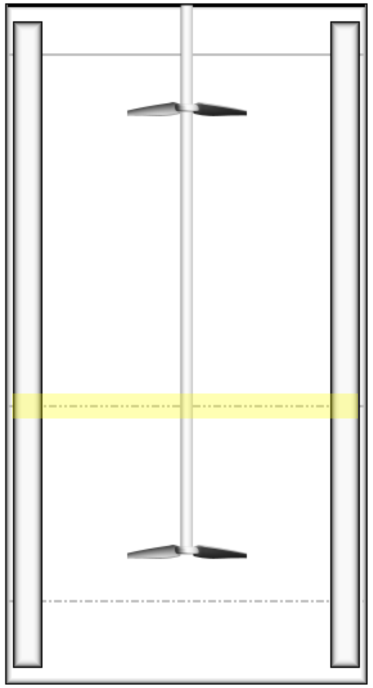

(a) Experiment
Single impeller


(b) KaeMix
Single impeller
CH/Z = 46%


(c) Experiment
Two impellers S/D = 3.0


(d) KaeMix
Two impellers S/D = 3.0
CH/Z = 95%


(e) Experiment
Two impellers S/D = 3.7

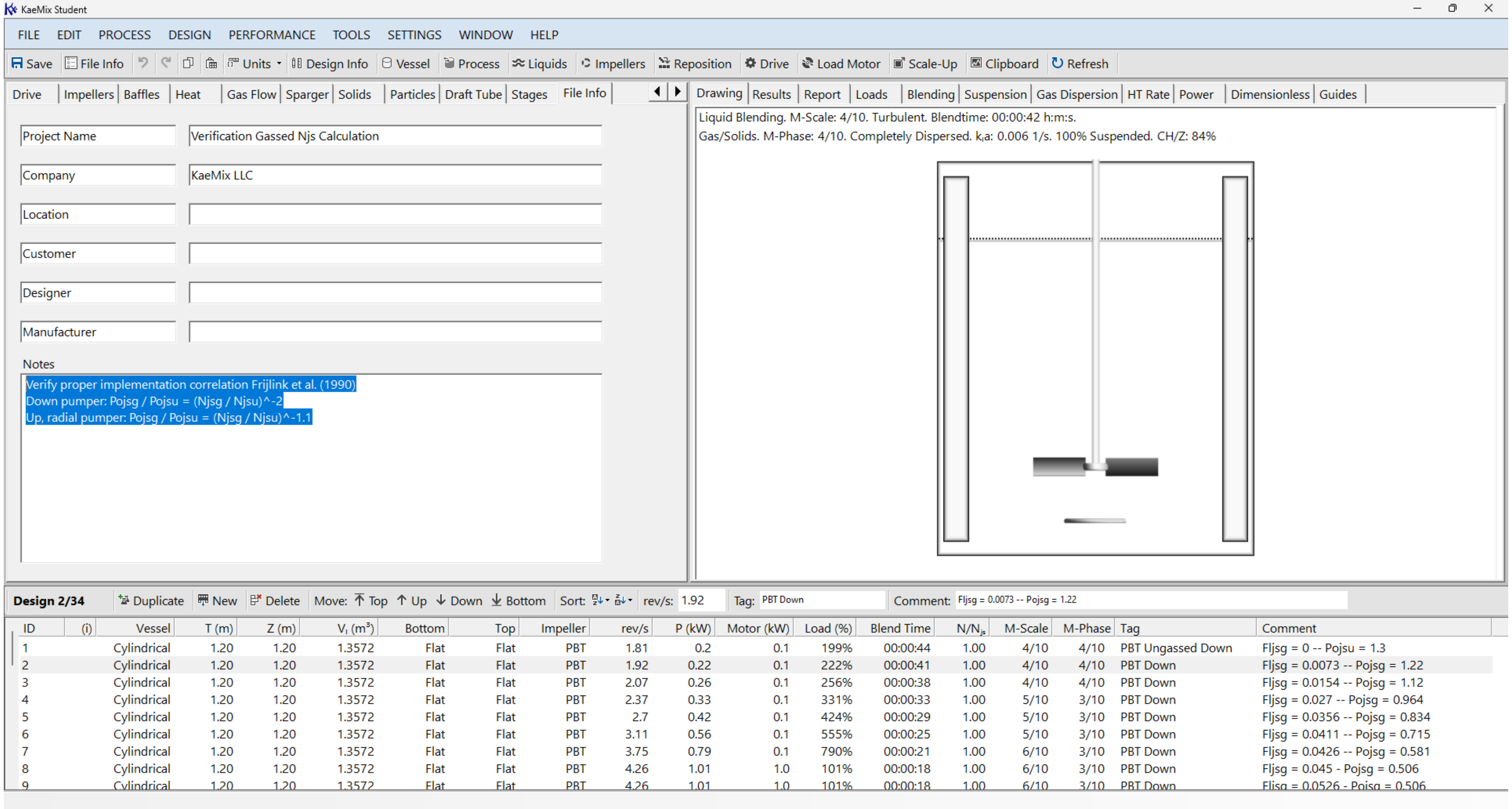

(f) KaeMix
Two impellers S/D = 3.7
CH/Z = 46%

The article describes several solids suspension experiments. In one experiment, with a single impeller, see figure (a), the height of the solids cloud CH is approximately 50-60% of the liquid level Z. For this configuration, KaeMix, figure (b) predicts CH/Z = 46%, slightly below the experiment. The dashed line indicating the cloud height in KaeMix is highlighted here in yellow. The lower dashed line (not highlighted) is the level of the solids bed if they all were settled. With two impellers spaced apart by S/D = 3, figure (c), the solids cloud is up to 80-90% of the liquid level. KaeMix, figure (d) predicts CH/Z = 95%. When the spacing between the impellers is increased to S/D = 3.7, figure (e), the flow between the impellers separates and the solids cloud height drops down again. KaeMix, figure (e), predicts CH/Z = 46%, correctly detecting that the spacing between the impellers is now too large for the solids to be distributed to the upper part of the vessel.

Reference: Bakker, Fasano, Myers (1994) *Effects of Flow Pattern on the Solids Distribution in a Stirred Tank.* 8th European Conference on Mixing
Notation: D = impeller diameter; S = impeller spacing; CH = cloud height; Z = liquid level.

Gassed Solids Suspension (1/2)

- File: KM-Verify-GassedSolids-Frijlink-Correlation.kaemix



Project Name: Verification Gassed Njs Calculation

Company: KaeMix LLC

Location:

Customer:

Designer:

Manufacturer:

Notes

Verify proper implementation correlation Frijlink et al. (1990)
Down pumper: Pojsg / Pojsu = (Njsg / Njsu)^-2
Up, radial pumper: Pojsg / Pojsu = (Njsg / Njsu)^-1.1

Liquid Blending. M-Scale: 4/10. Turbulent. Blendtime: 00:00:42 h:m:s.

Gas/Solids. M-Phase: 4/10. Completely Dispersed. k_la: 0.006 1/s. 100% Suspended. CH/Z: 84%

Design 2/34

rev/s: 1.92

Tag: PBT Down

Comment: Fljsg = 0.0073 -- Pojsg = 1.22

ID	(i)	Vessel	T (m)	Z (m)	V_l (m³)	Bottom	Top	Impeller	rev/s	P (kW)	Motor (kW)	Load (%)	Blend Time	N/N_{js}	M-Scale	M-Phase	Tag	Comment
1		Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	1.81	0.2	0.1	199%	00:00:44	1.00	4/10	4/10	PBT Ungassed Down	Fljsg = 0 -- Pojsu = 1.3
2		Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	1.92	0.22	0.1	222%	00:00:41	1.00	4/10	4/10	PBT Down	Fljsg = 0.0073 -- Pojsg = 1.22
3		Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	2.07	0.26	0.1	256%	00:00:38	1.00	4/10	4/10	PBT Down	Fljsg = 0.0154 -- Pojsg = 1.12
4		Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	2.37	0.33	0.1	331%	00:00:33	1.00	5/10	3/10	PBT Down	Fljsg = 0.027 -- Pojsg = 0.964
5		Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	2.7	0.42	0.1	424%	00:00:29	1.00	5/10	3/10	PBT Down	Fljsg = 0.0356 -- Pojsg = 0.834
6		Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	3.11	0.56	0.1	555%	00:00:25	1.00	5/10	3/10	PBT Down	Fljsg = 0.0411 -- Pojsg = 0.715
7		Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	3.75	0.79	0.1	790%	00:00:21	1.00	6/10	3/10	PBT Down	Fljsg = 0.0426 -- Pojsg = 0.581
8		Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	4.26	1.01	1.0	101%	00:00:18	1.00	6/10	3/10	PBT Down	Fljsg = 0.045 - Pojsg = 0.506
9		Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	4.26	1.01	1.0	101%	00:00:18	1.00	6/10	3/10	PBT Down	Fljsg = 0.0526 - Pojsg = 0.506

Gassed Solids Suspension (2/2)

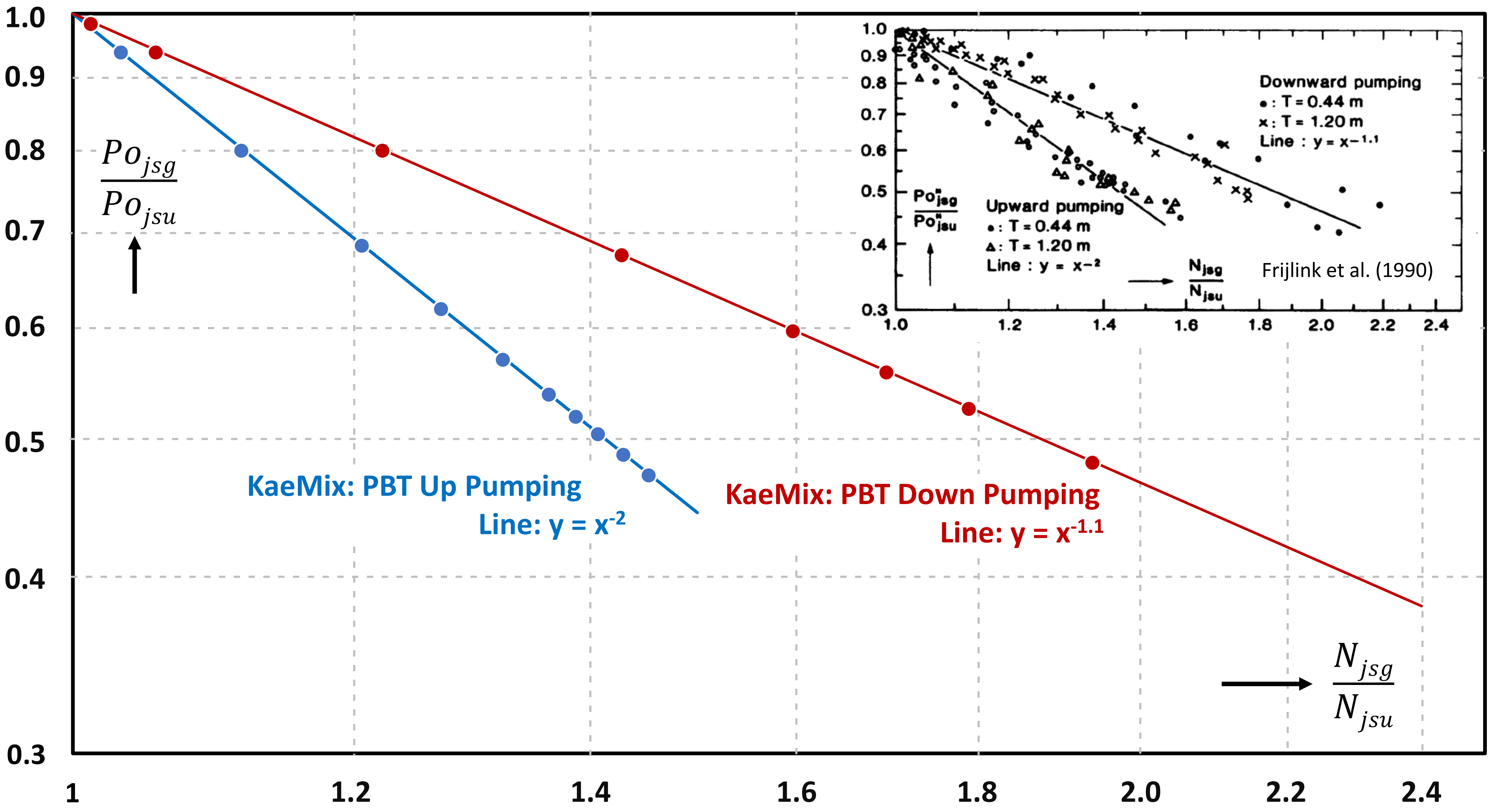
KaeMix calculations for gassed suspension speed N_{jsg} use the method presented by Frijlink et al. (1990).

This is based on the observation that on average:

$Po_{jsg}/Po_{jsu} = (N_{jsg}/N_{jsu})^c$

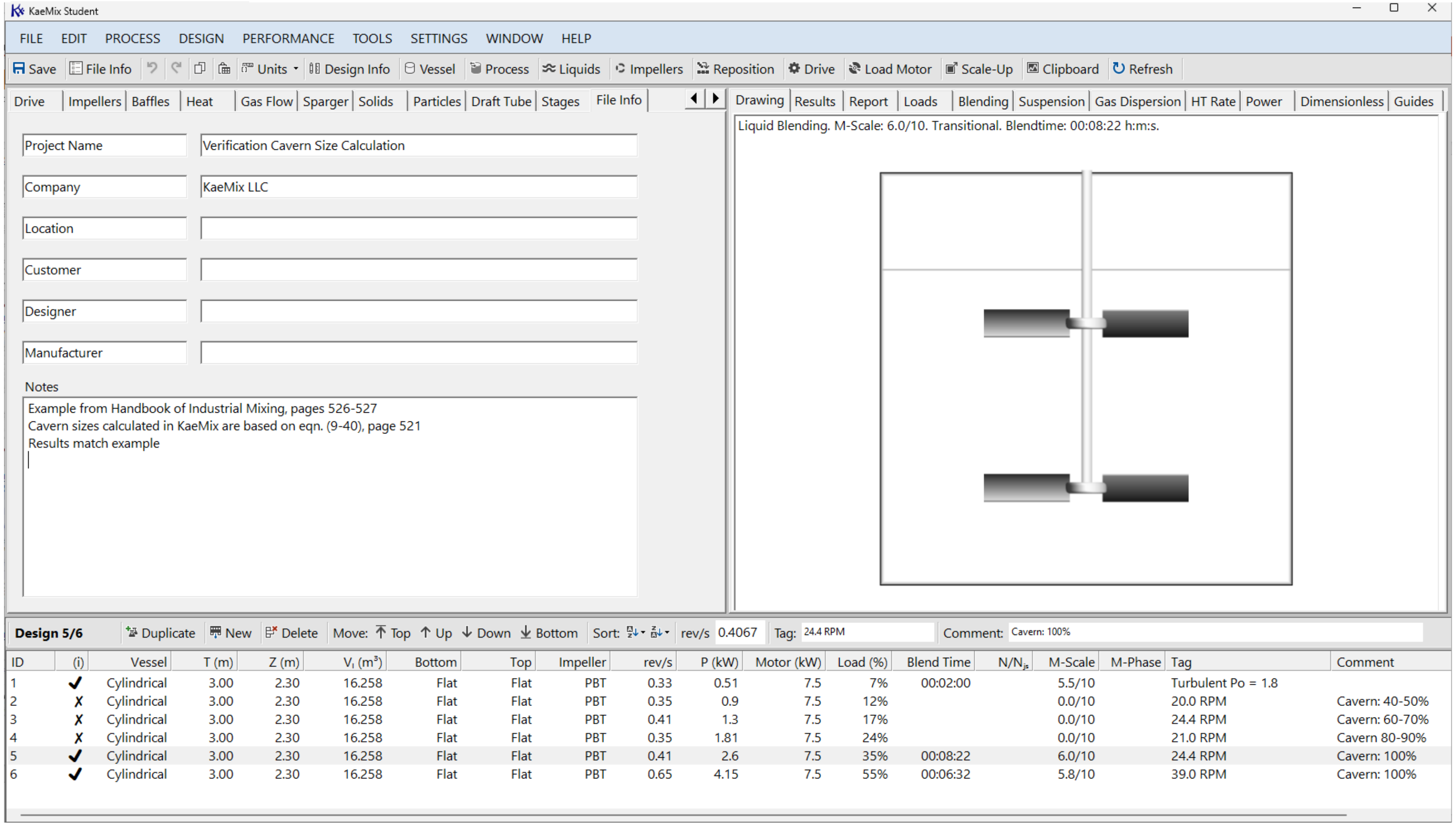
Here, c = -1.1 for down pumping impellers and -2 for up pumping and radial flow impellers.

KaeMix determines N_{jsg} using this relationship.



Cavern Size (1/3)

- File: KM-Verify-CavernSize-YieldStress-Fluid.kaemix



Project Name: Verification Cavern Size Calculation

Company: KaeMix LLC

Location:

Customer:

Designer:

Manufacturer:

Notes

Example from Handbook of Industrial Mixing, pages 526-527
Cavern sizes calculated in KaeMix are based on eqn. (9-40), page 521
Results match example

Liquid Blending. M-Scale: 6.0/10. Transitional. Blendtime: 00:08:22 h:m:s.

rev/s: 0.4067 Tag: 24.4 RPM Comment: Cavern: 100%

ID	(i)	Vessel	T (m)	Z (m)	V_l (m^3)	Bottom	Top	Impeller	rev/s	P (kW)	Motor (kW)	Load (%)	Blend Time	N/N_{js}	M-Scale	M-Phase	Tag	Comment
1	✓	Cylindrical	3.00	2.30	16.258	Flat	Flat	PBT	0.33	0.51	7.5	7%	00:02:00		5.5/10		Turbulent Po = 1.8	
2	✗	Cylindrical	3.00	2.30	16.258	Flat	Flat	PBT	0.35	0.9	7.5	12%			0.0/10		20.0 RPM	Cavern: 40-50%
3	✗	Cylindrical	3.00	2.30	16.258	Flat	Flat	PBT	0.41	1.3	7.5	17%			0.0/10		24.4 RPM	Cavern: 60-70%
4	✗	Cylindrical	3.00	2.30	16.258	Flat	Flat	PBT	0.35	1.81	7.5	24%			0.0/10		21.0 RPM	Cavern 80-90%
5	✓	Cylindrical	3.00	2.30	16.258	Flat	Flat	PBT	0.41	2.6	7.5	35%	00:08:22		6.0/10		24.4 RPM	Cavern: 100%
6	✓	Cylindrical	3.00	2.30	16.258	Flat	Flat	PBT	0.65	4.15	7.5	55%	00:06:32		5.8/10		39.0 RPM	Cavern: 100%

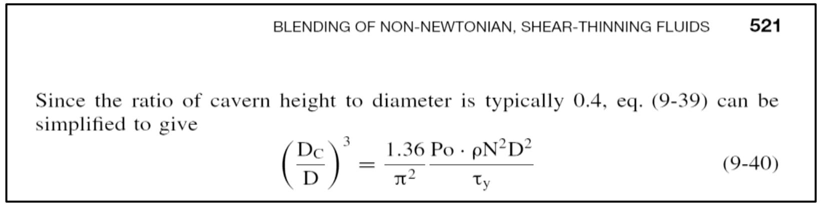
Cavern Size (2/3)

Grenville and Nienow* (2004) Example 9-5, pages 526-527	
T / Z	3.0 m / 2.3 m
Density	1560 kg/m^3
Viscosity (at 1/s)**	1 mPa.s
Yield Stress	18 Pa
Pitched Blade Turbine D	1.5 m
Power Number***	1.8 (6 blades, 45° angle, W/D=0.23)
One Impeller – 21.0 RPM	40-50% of Operating Volume
One Impeller – 24.4 RPM	60-70% (Cavern diameter in KaeMix matches example)
Two Impellers – 21.0 RPM	80-90% of Operating Volume
Two Impellers – 24.4 RPM	100% (Cavern size in KaeMix matches example)

** KaeMix cavern diameter calculations based on Grenville and Nienow (2004). Cavern aspect ratio for radial flow impellers also per Grenville and Nienow. Aspect ratio for axial flow impellers based on Benz (2012)*

*** Example does not specify the base viscosity, only the yield stress. Using 1 mPa.s in KaeMix setup. This does not affect the cavern size calculation*

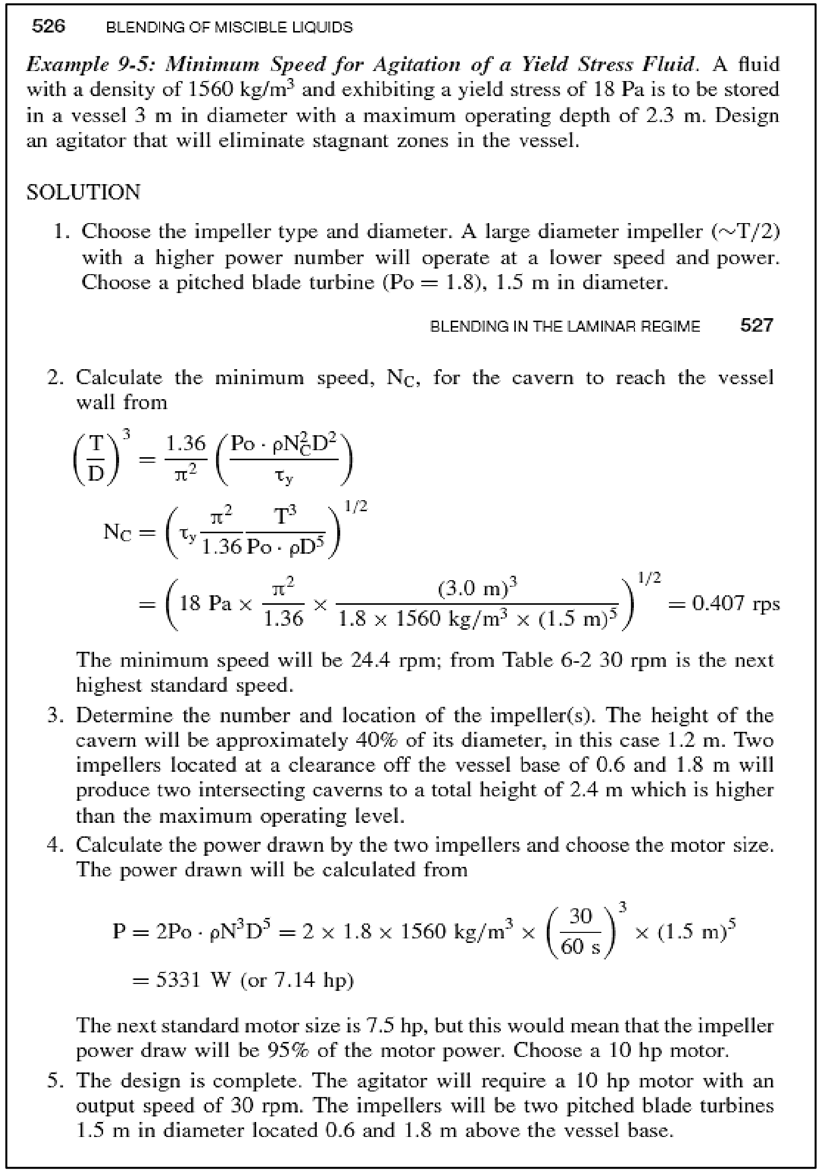
**** Example does not specify impeller number of blades or other geometry details but only that Po=1.8. Impeller geometry in KaeMix was specified to match this Po.*



BLENDING OF NON-NEWTONIAN, SHEAR-THINNING FLUIDS **521**

Since the ratio of cavern height to diameter is typically 0.4, eq. (9-39) can be simplified to give

$$\left(\frac{D_C}{D}\right)^3 = \frac{1.36}{\pi^2}\frac{Po \cdot \rho N^2 D^2}{\tau_y} \qquad (9\text{-}40)$$



526 BLENDING OF MISCIBLE LIQUIDS

Example 9-5: Minimum Speed for Agitation of a Yield Stress Fluid. A fluid with a density of 1560 kg/m^3 and exhibiting a yield stress of 18 Pa is to be stored in a vessel 3 m in diameter with a maximum operating depth of 2.3 m. Design an agitator that will eliminate stagnant zones in the vessel.

SOLUTION

1. Choose the impeller type and diameter. A large diameter impeller (~T/2) with a higher power number will operate at a lower speed and power. Choose a pitched blade turbine (Po = 1.8), 1.5 m in diameter.

BLENDING IN THE LAMINAR REGIME **527**

2. Calculate the minimum speed, N_C, for the cavern to reach the vessel wall from

$$\left(\frac{T}{D}\right)^3 = \frac{1.36}{\pi^2}\left(\frac{Po \cdot \rho N_C^2 D^2}{\tau_y}\right)$$

$$N_C = \left(\tau_y \frac{\pi^2}{1.36}\frac{T^3}{Po \cdot \rho D^5}\right)^{1/2}$$

$$= \left(18\ \text{Pa} \times \frac{\pi^2}{1.36} \times \frac{(3.0\ \text{m})^3}{1.8 \times 1560\ \text{kg/m}^3 \times (1.5\ \text{m})^5}\right)^{1/2} = 0.407\ \text{rps}$$

The minimum speed will be 24.4 rpm; from Table 6-2 30 rpm is the next highest standard speed.

3. Determine the number and location of the impeller(s). The height of the cavern will be approximately 40% of its diameter, in this case 1.2 m. Two impellers located at a clearance off the vessel base of 0.6 and 1.8 m will produce two intersecting caverns to a total height of 2.4 m which is higher than the maximum operating level.
4. Calculate the power drawn by the two impellers and choose the motor size. The power drawn will be calculated from

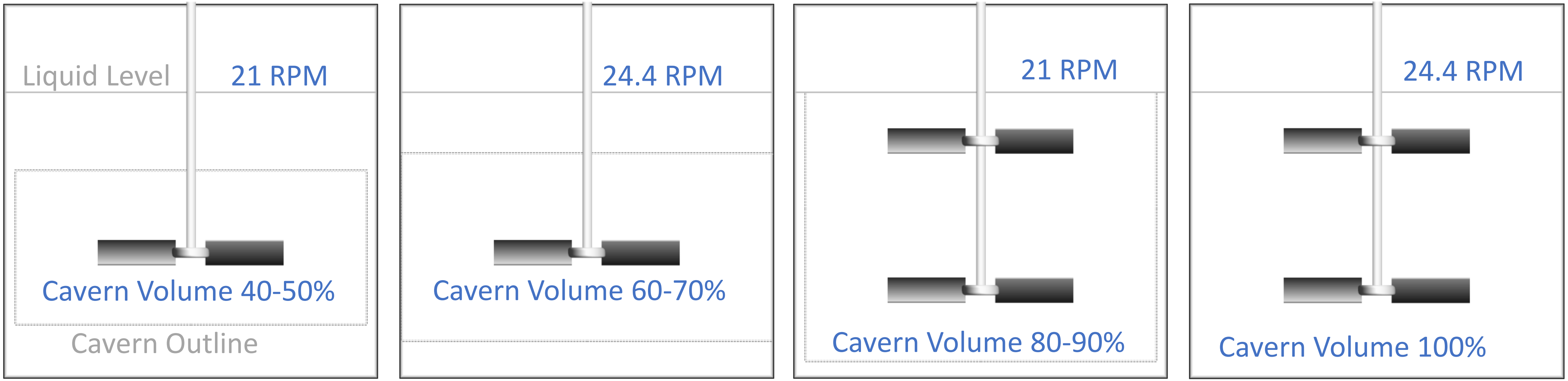
$$P = 2Po \cdot \rho N^3 D^5 = 2 \times 1.8 \times 1560\ \text{kg/m}^3 \times \left(\frac{30}{60\ \text{s}}\right)^3 \times (1.5\ \text{m})^5$$

$$= 5331\ \text{W (or 7.14 hp)}$$

The next standard motor size is 7.5 hp, but this would mean that the impeller power draw will be 95% of the motor power. Choose a 10 hp motor.

5. The design is complete. The agitator will require a 10 hp motor with an output speed of 30 rpm. The impellers will be two pitched blade turbines 1.5 m in diameter located 0.6 and 1.8 m above the vessel base.

Cavern Size (3/3)



Cavern volumes drawn by KaeMix for several conditions

END