K KaeMix

KaeMix Student 2025 Verification Guide

KaeMix Documentation May 27, 2025 www.kaemixllc.com support@kaemixllc.com



<u>Summary</u>

- 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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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 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, comparison: KM-Verify-Solids-Njs-LanzafameKehn.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

KaeMix Student	:															-	
ILE SEND	EDIT PROCE	SS DES	SIGN PER	FORMANC	E CREATE	TOOLS	SETTINGS	WINDC	W HEL	Р							
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esign Vesse	el Process Lic	uids Dri	ive Impe	llers Baffle	es Solids	Gas Flow	Sparger F	ile Info		D	awing Resu	ults Report	Loads	Blending	Suspension Gas Dispersion Power	Dimensionless Guides	
Impel	llers @ Edit Sets	1-4	C Edit Set	s 5-8						Li	quid Blendir	ig. M-Scale: 0	.8/10. Tur	bulent. Ble	endtime: 00:04:53 h:m:s.		
		🔽 Set 1	\Leftrightarrow	🗆 Set 2	2	🗆 Set	3	🗆 Se	t 4								
	Connected To	Main Dr	ive •	•													
	Style	Disk Tur	- thine	-													
	Type	Duchter															
	Dump Direction	Kushtor															
	Pump Direction	Radial	<u> </u>														
	Diameter (m)	1															
	Blade Width (m)	0.2															
N	umber of Blades	6	•														
Blade	e Angle (degrees)																
Num	ber of Impellers	1															
First Botto	m Clearance (m)	0.7															
Last Botto	m Clearance (m)	0.7															
Lust botto	Nin Cicularianee (m)			_													
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				1													
Impelle	r Power Number	5.5]													
Diameter /	' Tank Ratio (D/T)	0.5															
Blade W	/idth Ratio (W/D)	0.2															
Clearance /	′ Tank Ratio (C/T)	0.35															
Blade Pitch	/ Diameter (P/D)																
	ta Dual' i	- N	. P* Dala		А Тана А Ц	.L. Davi	d. Dates	Carto Di	21. Dr	N4 6	T DT C	blada U/D	1/1 0.		- 1055 Do - 55 No - 075		
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D	Vessel	T (m)	Z (m)	V _I (m³)	Bottom	Тор	Impeller	RPM	P (kW)	Motor (kW)	Load (%)	Blend Time	N/N _{js}	M-Scale	Multiphase Tag	Comment	
	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	6.0 6.0	5.3E-03	10	0%	00:04:53		0.8/10	RI - 6 blade - H/D=1/5	Re = 1.0E5 - Po = 5.5 - 1 Re = 1.0E4 - Po = 5.29 -	Na =
- •	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	6.0	4.7E-03	10	0%	00:07:43		0.7/10		Re = 2.0E3 - Po = 4.69 -	Nq =
• •	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	6.0	4.3E-03	10	0%	00:13:15		0.6/10		Re = 1.0E3 - Po = 4.28 -	- Nq
5 🗸	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	6.0	4.2E-03	10	0%	00:16:32		0.6/10		Re = 800 - Po = 4.15 - N	Nq =
o 🗸	Cylindrical	2.00	2.00	6.2832	Flat	Flat	RDT	6.0	4.0E-03	10	0%	00:22:35		0.6/10		Re = 600 - Po = 3.99 - N	Na = 1
7	Cylindrical	2 () ()	2 00	6 10 1	LIST	LIST		6.0			()02	00.26.27		06/10		$P_0 = 400 - P_0 = 201$ N	la - (

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Power Number vs. Reynolds Number



KaeMix Student Verification Guide

Blending – M-Scale (1/4)

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



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	5.8 \rightarrow Matches article				

Analysis of power/speed relationship for turbine agitators

has a specific gravity of 1.0 and a viscosity of 5,000 cp. second trial calculation using revised assumptions. What is the size of the agitator that will give a dynamic ft/min? What will be the required power and speed for of impeller speed yields: 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 becomes: 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/ft³. 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 ft². 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:

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

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 viscosity correction factor, $C_{\rm F}$, for an impeller $N_{\rm Re} = 458$ midrange value of 0.3. Hence, the impeller diameter be- as 0.985. Hence, the corrected turbine diameter, D_{T} , is comes:

D = 9.47(0.3)(12) = 34.09 in

From Fig. 2, we must establish a pumping number, N_0 , 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 $N_0 = 0.8$ for D/T = 0.3.

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

$N_0 = Q/ND^3$

where O 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:

 $N = 2.534/(0.8)(34.09/12)^3 = 138.2$ 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 cation.

A 5,000-gal reactor will be used to agitate a fluid that an $N_0 = 0.8$ for a D/T ratio of 0.3. We must now make a Based on the previously calculated $N_{R_e} = 344$, we pick response corresponding to a bulk fluid velocity of 36 an $N_0 = 0.55$ for D/T = 0.3. The second trial calculation

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

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

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

Agreement between an $N_0 = 0.55$ 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 $N_0 = 0.60$ from Fig. 2 for a D/T = 0.3. The third trial calculation of impeller speed yields:

 $N = 2,534/(0.6)(34.09/12)^3 = 184.2$ 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 $N_0 = 0.60$ 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 computed from Eq. (4) as:

```
D_{\pi} = 34.09/0.985 = 34.61 in
```

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

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

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, bulkfluid-velocity matrix (Tables II and III) for ease of appli-

*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 сР
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	$1.2 \rightarrow Matches$ article	2.6 → Matches article	9.7 \rightarrow Matches article

	Example 1	Example 2	Example 3
tem			
Vessel	Fig. 4a	Fig. 4b	Fig. 4c
Nozzle or mounting height, in	12	6	6
Туре	Flat	ASME	Dished
Top head Depth, in	0	16	8
Diameter, T, in	138	96	60
Straight side, in	144	150	96
Bottom head	ASME	ASME	Dished
(Depth, in	24	16	8
Overall height, in	180	188	118
Fluid batch			
Capacity cal	000	214 may 214 min	50
Depth in	926 max.	16 max 16 min.	52 max.
Straight side	24 max.	to max. to min.	o max.
Capacity gal	9 074 max	4 686 may 2 632 min	000
Depth, in	140 max	150 max 84 min	990 max, 81 max
Total,	The max.	100 1101 01 1111	or max.
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, Sa	1.05	1.3	0.95
Viscosity, µ, cp	4,900	5,000	25,000
Equivalent volume, Veq, gal	10,500	6,500	990
a of anitation			Children and an and an and an and
	See more management		
Alternate		3	10
war and chaft enough		-	'
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.	-	-	-
uipment selection			NUCLEAR DESCRIPTION
Number of turbines	1	2	2
Turbine, blade type	Pitched	Pitched	Pitched
Bottom clearance,	11/217 - 55	T/2 - 22	T/0 - 00
Lower turbine, in	(1/3)2 = 55	1/3 = 32	1/3 = 20
Shaft length / in	125	156	(2/3/2 = 59
Turbine spacing S in	-	79	30
Turbine diameter <i>D</i> in		15	39
Initial selections	I SALA SALASSA		
1.	32	26	36
2.	-	27	38
3.	- 100	30	-
4.	-	34	
Alternate selections			
1.	-	-	28
2.	-	-	37
3.	-	-	-
4.	-	-	-
Battles			
Location ⁰	4	4	None
Width in	90	90	-
Length in	144	150	
	144	100	

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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	$2.0 \rightarrow$ Matches article	$3.4 \rightarrow$ Matches article

	Maximum allowed Z/T values								Power number for impellers as a function of D/T			
	N _{Re} range	Hig efficie impe	ih- ency eller	Four-bi 45-c pitcl impe	aded, deg hed eller	Four-bi flat o blac impe	laded r six- ded eller	1.5		C/T = 1/3 Four-bladed, uitched impeller		
		Single	Dual	Single	Dual	Single	Dual	Np				
	10 - 100	0.9	1.7	0.8	1.5	0.6	1.2	1.0				
	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	0.5		Three-bladed, high efficiency (HE-3) pitched impeller		
	> 10,000	1.5	2.4	1.2	1.9	0.8	1.6					
	For single impeller For dual impeller	ers: $Z/6 \le$ rs: $Z/8 \le$	$C \le Z/2;$ $C \le 3Z/8$	Standard ($k; Z/2 \leq C$	C = Z/3 + $S \leq 3Z$	/4; Standa	rd C =	0.0 10 ²	10	1 ³ 10 ⁴ 10 ⁵ 10 ⁵		
		610, U	+0=0	640	-		-	6		Reynolds number		
	TABLE 2. The whether the agit	maximun ators hav	allowe	ed Z/T val	ues var impelle	y, depen rs	ding on	-	- D/T = 0.2	D/T = 0.3 D/T = 0.4 D/T = 0.5		
	The character pressed as: $v^* \propto N_q ND \left(\frac{D^2}{T^2}\right)$ This character pressure of the second seco	ristic ve) teristic	locity c velocit	an be ex (7 y scale:	$\begin{pmatrix} C_{\infty} \\ acc \\ U(0) \\ wh \\ s \\ The$	The wording t $() = 1 - e^{-1}$ ere $k_{\rm m}$ i e above	niformi o an ex ^{k_{at} is the r equatio}	ity usuall ponential nixing-rat m can be	y increases function: (10) æ constant. rearranged	FIGURE 3. When called upon to load an ag itator impeller to a given power level, one can use Equation 2 to calculate the required diameter of the impeller from the power number For certain applications, such as acid-base neutralizations, it is desir		
	geometrically a	nd becor	nes		to	yield an	equation	on for the	blend time	able to predict the maximum and mini-		
For	most tu	irbin	e a	pplic	catio	ons,	re-	a certai	n degree of	The following equations are obtained		
placir	ng a pitche	ed-bl	ade	imp	elle	r wit	h a		(11)	from rearrangements of the definition		
high-	efficiency	unit	res	ults	in a	sign	nifi-			can be used to estimate the maximum		
cant i	mprovem	ont i	n th	no do	mo	aof	arri	consta	ants	and minimum concentrations at a spec ified time t		
tation	inprovem	Enti		ie ue	gree	1 -	agi-	a	b	$C_{\min}(t) = C_i + (C_{\infty} - C_i)U$		
tation	intensity	. 101	exa	ampi	e, a	1.0-	KW	1.06	2.17	$C_{\max}(t) = C_n - (C_n - C_m)U$ (12)		
agitat	or operat	ing	at a	i sha	ift s	speed	t of	1.01	2.30	where $C_{\min}(t)$ and $C_{\max}(t)$ are the mini-		
0.75	rotations/	s (48	5 rp	m) i	in a	a 50-	-m ³	0.641	2.19	mum and maximum concentrations anywhere in the tank at time t . C_i and C_i are the initial and final concentrations		
squar	e-batch (2	$T = \frac{1}{2}$	= 1)	vess	el e	quip	ped	0 272	1.67	tion of the added material in the bulk		
with a	a 1.558-m	-dia.	hig	h-ef	ficie	ncy	im-	The mixi	ng-rate con-	fluid, respectively. C _a refers to the con-		
peller	provides	S. 0	fius	st ab	ove	3 in a	a 1-	rbulent f	low regimes	The dimensionless mixing-rate con-		
Pag	viscosity	flui	d	In	ont	ract		The ble	and time for	stant, k _m /N, in standard baffled tanks is a function of impeller Reynolds num		
1 1 5	viscosicy	1 I	111	11 (11	, a	a pitche nger than	d-blade tur- that with a	ber $(N_{\rm Re})$ and geometry. When $N_{\rm Re}$ >		
1.134	-m-dia. pi	tche	d-bl	ade	imp	eller	r in	ler		10,000, k _m /N is only a function of geom- etry, and is independent of N _n . For		
the sa	ame batch	ves	sel (draw	s th	ie sa	me	summa	y	fully turbulent conditions in standard		
power	to produ	$\operatorname{ce} S_{I}$	of,	just	abo	ve 2.		bladed	Pitched- blade	perimentally from N , D , T and Z using the following relationship:		
	degree of unifor	red to a rmity aft	er a m	a certair aterial is		Ter -	im		impeller	$\sum_{a} \sqrt{D} D^{a} T^{0.5}$		
	added to a tan	k is one	of the	most fre	19	9, turb in s		4 480	0 3 77	$k_{m} = a N \left[\frac{\tilde{T}}{T} \right] \left[\frac{1}{\tilde{Z}} \right] $ (13)		
	ments. The uni	formity	ocess of mixi	require ing is de	e e	Re	10	1.00	1.00	The constants a and b are provided		
	fined as:				N	0		2.08	3.70	in Table 3, as a function of impeller		
	$U = 1 - \frac{\left[\Delta C(t)\right]_m}{\left[\Delta C(0^*)\right]}$	88		(9	f.	and .		2.65	2.50	style in the turbulent range (N_{Re}) >10,000).		
	Hore AC is th	nax o denicit	ion F	n the e	μ		1	50.0	50.0	Unless otherwise specified, blend		
	erage tank cor	centrati	on, de	noted by	f			1.06	1.13	quired to achieve 99% uniformity and		
					to	, in s		320	483			

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Blend Time (1/2)

• File: KM-Verify-BlendTime.kaemix

K* K	aeMix Stud	ent															-	o x
FIL	E SEN	D EDIT PR	OCESS	DESIGN	PERFORMA	NCE CRE	ATE TOOLS	SETTINGS	WIND	OW F	HELP							
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Des	ign Ve	ssel Process	Liquids	Drive Ir	npellers Ba	ffles Soli	ds Gas Flo	w Sparger	File Info			Drawing R	esults Repor	t Loads I	Blending Susp	pension Gas Dispersio	on Power Dimensionless Guides	
								1.0		_	1	Liquid Blend	ding. M-Scale	: 1.6/10. Turbi	ilent. Blendtim	ne: 00:04:17 h:m:s.		
P	roject Na	me	▼ Verif	y Blend Tim	ne Calculatio	ı												
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										-								
R	eference		▼ Fasa	no (1994) A	dvanced Im	oeller Geon	netry Boosts	iquid Agitatio	on									
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P	roject No	tes																
	D 1-2 Ble	nd Time	% with DP	C should be	50% higher	than for U	. NI											
Í	aeMix Th	-99% HF-N =	1:52. PBT =	2:51. Blend	d time PBT is	53% longe	r than with H	F-N.										
				(-	_		ſ		1				
De	sign 2/2	*≊ Dupl	icate 🛱 N	New ⊫ [®] De	elete Move	: ↑ Top 1	`Up ↓ Dow	n ⊻ Bottom	Sort: 2	↓• <u>6</u> ↓•	RPM: 67.8	Tag: PBT	D/T=0.222	Comm	ent: Tb-99% =	= 00:02:51		
ID 1	1	Vessel	T (m)	Z (m)	V ₁ (m ³)	Bottom	Top	Impeller	RPM 67.8	P (kW)	Motor (kW)	Load (%)	Blend Time	N/N _{js} M-S	cale Multiph	HE-N D/T-0.297	Comment	KaeMix - O
2	~	Cylindrical	4.00	4.00	50.265	Flat	Open	PBT	67.8	1.11	2.0	55%	00:02:30	1.6	5/10	PBT D/T=0.222	Tb-99% = 00:02:51	

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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

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Design Vessel Process Liquids Drive Impellers Battles Solids Gas How Sparger File Into	Drawing Results Report Loads Blending Suspension Gas Dispersion Power Dimensionless Guides
Project Name Verify Flooding Prediction Rushton & Smith Impeller	Gas Dispersion. Flooded (0/4). k _i a: 0.044 1/s
Company V KaeMix LLC, 2022	
Reference Bakker (1994) How to Disperse Gases in Liquids	
Project Notes	
Rushton impeller system is flooded and the Smith impeller system is dispersing, as in the article's example	
Design 1/2 [™] Duplicate [™] New [™] Delete Move: [↑] Top [↑] Up [↓] Down [↓] Bottom Sort: [™] / ₂ • [*] / ₂ • [*] / ₂ •	RPM: 67.8 Tag: Comment: Flooded
ID Φ Vessel T (m) Z (m) V ₁ (m ³) Bottom Top Impeller RPM P (kW)	Motor (kW) Load (%) Blend Time N/N _{je} M-Scale Multiphase Tag Comment
1 Cylindrical 2.00 2.00 5.8643 Ellipse Ellipse RDT 67.8 1.54 2 ✔ Cylindrical 2.00 2.00 5.8643 Ellipse Ellipse SDT 67.8 1.37	3.0 51% 00:00:42 4.0/10 statistic Flooded 3.0 46% 00:00:43 4.2/10 ##statistic Dispersing

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
$FI_g = N_A$	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 O	MAKEUP OF A REACTOR				
Parameters	Values				
T	2.0 m				
D	0.80 m				
N	1.13 s ⁻¹				
Q_	0.12 m ³ /s				
u	0.001 Pa-s				
p	1,000 kg/m ³				
N.	0.21				
NEr	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: $N_{\rm Fr}$ = 0.12; and $N_{\rm A}$ at 0.18 is less than $N_{\rm A,FL}$ 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.

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Gas Dispersion (3/5)



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Gas Dispersion (4/5)



- 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 m³ vessel (177 ft³ 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/ft³ 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
Т	1.3	m
Н	3.77	m
V	5	m ³
Ро	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 · s

Gas Dispersion (5/5)



Example 11-2: Power Demand of a Large Fermenter. The agitator in a 20 m³ 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/m³ (3 hp per 1000 gal)? See Example 11-1 for physical properties.

Table	11-6

Name	SI Value	SI Unit
V	20	m ³
Т	2.34	m
Н	4.67	m
D_1	0.934	m
D_2	0.712	m
Ν	2.11	s ⁻¹ or rps
Po ₁	1	
Po ₂	5	
Pu ₁	6670	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

• 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)

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Suspension – Literature Comparison (1/2)

• File: KM-Verify-Solids-Njs-LanzafameKehn.kaemix

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✓ Solids	Suspension								Resul	ts Lie	quid Blendir	g. M-Scale: 2.	9/10. Tu	rbulent. Bl	endtime: 00:00:29 h:m:s.		
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		Solids Den	sity (kg/m³)	2500													
		Particle Diar	meter (mm)	0.121		•											
		Settl	ing Velocity	Specify		•											
	Particle Fre	ee Settling Ve	locity (m/s)	0.0167										I			
	Hinder	ed Settling Ve	locity (m/s)	0.0164													
	Solids Wei	aht / Mixture	Weight (%)	1		_							H				
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	Cylindrical	0.45	2 (m) 0.45	0.0646	ASME	Flat	HF-N	205.3	3.2E-03	0.10	LOAD (%) 3%	00:00:29	1.01	2.9/10	*★★☆ 01/A310/121um/1%	Exp Nis: 205.3 RPM. Kae	Mix Nis: 204
2 🗸	Cylindrical	0.45	0.45	0.0646	ASME	Flat	PBT	186.3	3.2E-03	0.10	3%	00:00:36	0.96	1.9/10	★★☆☆ 02/PBT/121um/1%	Exp Njs: 186.3 RPM. Kae	Mix Njs: 19
3 🗸	Cylindrical	0.45	0.45	0.0646	ASME	Flat	HF-N	262.2	6.8E-03	0.10	7%	00:00:23	1.03	3.7/10	★★★☆ 03/A310/391um/1%	Exp Njs: 262.2 RPM. Kae	Mix Njs: 25
4	Cylindrical	0.45	0.45	0.0646	ASME	Flat		249.6	7.7E-03	0.10	8%	00:00:27	1.03	2.6/10	★★☆☆ 05/A210/121um/1%	Exp Njs: 249.6 RPM. Kae	Mix Njs: 24
⁵ ✓	Cylindrical	0.45	0.45	0.0646	ASIVIE	Flat	HF-N DRT	237.9	5.2E-03	0.10	5% 6%	00:00:25	0.94	3.4/10	★★☆☆ 06/PRT/121um/5%	Exp NJS: 237.9KPM. Kael Evp NJs: 222.1 RDM Kael	Mix Nis: 25:
7	Cylindrical	0.45	0.45	0.0646	ASME	Flat	HF-N	348.2	1.6E-02	0.10	16%	00:00:17	1.10	5.0/10	★★★☆ 07/A310/391um/5%	Exp Njs: 348.2 RPM. Kae	Mix Njs: 31

Suspension – Literature Comparison (2/2)

KaeMix results vs. experimental data Lanzafame and Kehn (2022) **RPM**_{is} **RPM**_{is} Weight <u>%</u> D (inch) Setup d_p (μm) Type **Experimental KaeMix** 121 1 7.6 A310 205.3 203.8 1 2 121 6.0 PBT 186.3 194.7 1 3 319 7.6 A310 262.2 254.4 1 500 6.0 249.6 319 1 PBT 243.3 4 450 5 7.6 121 5 A310 237.9 253.5 400 6 121 5 6.0 PBT 222.1 242.0 7 319 5 7.6 A310 348.2 315.8 350 8 319 5 6.0 PBT 316.1 301.8 300 9 121 10 7.6 A310 254.8 283.1 250 10 121 10 6.0 PBT 239.6 270.3 11 319 10 7.6 A310 376.9 352.8 200 12 319 10 6.0 PBT 335.9 337.2 150 13 121 15 7.6 A310 258.3 305.9 100 14 15 6.0 240.8 292.1 121 PBT 15 7.6 319 15 A310 399.7 381.8 50 16 319 15 6.0 PBT 353.9 365.0 0

COMPARING PREDICTED JUST SUSPENDED SPEED VS EXPERIMENTAL JUST SUSPENDED SPEED FOR AXIAL FLOW IMPELLERS IN A STIRRED VESSEL

2022 VIRTUAL NAMF ANNUAL MEETING



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Solids Cloud Height (1/2)

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



Solids Cloud Height (2/2)



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.

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Gassed Solids Suspension (1/2)

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

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ID O	Vessel	T (m)	Z (m)	V₁ (m³)	Bottom	Тор	Impeller	RPM	P (kW)	Motor (kW) Load (%)	Blend Time	N/N _{js}	M-Scale	Multiphase	Тад	Comment	
	Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	96.6	0.14	0.25	5 56%	00:00:49	1.00	4.1/10	****	PBT Ungassed Down	Pojsu = 1.30	
3	Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	97.2	0.14	0.2	5 59%	00:00:49	1.00	4.1/10	****	PBT Down	Pojsg = 1.29 Pojsg = 1.27	
4	Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	113.4	0.19	0.50	38%	00:00:42	1.00	4.5/10	****	PBT Down	Pojsg = 1.09	
5	Cylindrical Cylindrical	1.20 1.20	1.20 1.20	1.3572 13572	Flat Flat	Flat Flat	PBT	138.0 154.2	0.28	0.7	5 37%	00:00:35	1.00 1.00	5.1/10 5.5/10	****	PBT Down PBT Down	Pojsg = 0.878 Pojsg = 0.776	
7	Cylindrical	1.20	1.20	1.3572	Flat	Flat	PBT	163.8	0.38	1.0) 38%	00:00:29	1.00	5.7/10	****	PBT Down	Pojsg = 0.726	

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



BLENDING OF NON-NEWTONIAN, SHEAR-THINNING FLUIDS 521

Cavern Size (2/3)

Grenville and Nienow* (2004) Example 9-5, pages 526-527

т/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.

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KaeMix Student Verification Guide

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

$$\left(\frac{D_{\rm C}}{D}\right)^3 = \frac{1.36}{\pi^2} \frac{\mathrm{Po} \cdot \rho \mathrm{N}^2 \mathrm{D}^2}{\tau_{\rm y}} \tag{9-40}$$

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/m³ 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 (\sim 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, $N_{\mbox{C}},$ for the cavern to reach the vessel wall from

$$\begin{split} \left(\frac{T}{D}\right)^3 &= \frac{1.36}{\pi^2} \left(\frac{Po \cdot \rho N_C^2 D^2}{\tau_y}\right) \\ N_C &= \left(\tau_y \frac{\pi^2}{1.36} \frac{T^3}{Po \cdot \rho D^5}\right)^{1/2} \\ &= \left(18 \ Pa \times \frac{\pi^2}{1.36} \times \frac{(3.0 \ m)^3}{1.8 \times 1560 \ \text{kg/m}^3 \times (1.5 \ \text{m})^5}\right)^{1/2} = 0.407 \ \text{rps} \end{split}$$

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 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 volumes drawn by KaeMix for several conditions

END