Using *k*-Factor to Compare Rotor Efficiency

Most researchers refer to the maximum speed of a rotor to compare efficiency. This can be misleading, however, since other factors such as the geometry of the tube or temperature contribute to rotor performance and must be considered before a valid comparison between similar rotors can be made. Some rotors are more efficient at slower speeds than a comparable rotor at higher speeds, simply because of the influence of these additional factors. So, we recommend using the term *k*-factor, rather than maximum speed, to compare centrifugation labware.

The *k*-factor is a common parameter that describes the efficiency of a centrifuge-rotor system, although temperature is still overlooked. Temperature complicates the determination and cannot be used in a simple formula; however, it can be managed in programs such as Beckman Coulter's eXPert software that factors in the temperature and corrects for buffer viscosities. *k*-factor, however, is still an excellent determination for rotor efficiency, as it includes all parameters to replicate a centrifugation step and clearly defines the proficiency of a centrifuge-rotor system.

The Determinants of *k*-Factor

The most important contributors to rotor efficiency are the maximum speed, maximum radius (r_{max}), and minimum radius (r_{min})—all of which contribute to the maximum *g*-force generated by the rotor. Firstly, the greater the minimum radius, the greater the centrifugal force at the top of the tube, and the faster the separation will proceed. Furthermore, the centrifugal force at the r_{min} defines the minimum size of a particle to start sedimentation. Another factor that has a direct bearing on rotor efficiency is the total pathlength of the rotor, or the difference between maximum and minimum radius. Shorter pathlengths mean particles have less distance to travel before pelleting against the tube wall. Pathlengths in similar rotors are a function of the diameter of the sample tube and the angle at which the tube is held. A more sharply angled tube generally results in a shorter pathlength. A simple measure of overall rotor efficiency that takes into consideration these variables is the *k*-factor, where:

$$k = \frac{2.533 \times 10^5 \times \ln(r_{max}/r_{min})}{(RPM/1000)^2} \qquad [1]$$

A lower *k*-factor corresponds to a more efficient rotor.

Comparative Efficiencies of Two 70,000 rpm Rotors

Applying the aforementioned efficiency factors to runs of the Beckman Coulter Type 70.1 Ti and Type 70 Ti rotors yield interesting results. The following example demonstrates how the Type 70.1 Ti at 450,000 × *g* will actually pellet material faster than a Type 70 Ti at a

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higher RCF (504,000 x *g*) when both are run at the same rotations per minute (70,000 rpm). As you can see in Table 1, the geometry of the tube cavity for the Type 70.1 Ti serves to decrease the maximum radius of the rotor (leading to a lower *g*-force) but also decreases the pathlength of the particles within the sample tube. The net effect of this reduced pathlength is a more favorable *k*-factor for the Type 70.1 Ti, resulting in more than 18% faster pelleting time than in the Type 70 Ti.

Table 1. Rotor Specifications.

Rotor Type	Type 70 Ti	Type 70.1 Ti
Maximum speed	70,000 rpm	70,000 rpm
Maximum radius (r_{max})	91.9 mm	82 mm
Minimum radius (r_{min})	39.5 mm	40.5 mm
Maximum *g*-force	504,000 x *g*	450,000 x *g*
Total pathlength	52.4 mm	41.5 mm
k-factor	44	36

Bovine Serum Albumin (BSA) is a common protein in research utilized for a multitude of purposes with a sedimentation coefficient (*s*) of 4.4s. Using the previous *k*-factors calculated in Table 1, for example, if an experimenter desired to pellet BSA using a Type 70 Ti rotor, the pelleting time can be calculated as such, where *t* is the run time in hours required to pellet particles of known sedimentation coefficient (in Svedberg units, s):

$$t = \frac{k}{s} = \frac{44}{4.4} = 10 \text{ } hours \qquad [2]$$

This simple calculation helps researchers save valuable time, and spin for the most efficient duration. In comparing the run time for the Type 70.1 Ti with BSA by substituting a *k*-factor of 36 generates a time of 8 hours, 11 minutes, demonstrating that a rotor with a smaller maximum *g*-force can actually be more efficient.

Relating Run Time Between Labware

Two popular, high-performance rotors in the Beckman Coulter, Inc. line are the SW 28 and the SW 32 Ti. To compare run times between two rotors in order to duplicate a particular centrifugation step, a researcher only needs to know the *k*-factor of each rotor and the duration of the run from a previous method. Use the following equation, where k_1 and k_2 are the *k*-factors of the SW 32 Ti and SW 28 respectively, t_2 is the duration of a previous protocol's run, and t_1 is the unknown spin time for the SW 32 Ti rotor:

$$\frac{t_1}{k_1} = \frac{t_2}{k_2} \qquad [3]$$

$$\frac{t_1}{204} = \frac{12 \text{ } hrs}{246}$$

$$t_1 = 9 \text{ } hrs, \text{ } 57 \text{ } min.$$

This is another simple calculation which facilitates researchers in comparing methods between 2 different centrifuge-rotor systems. This equation helps to equally sediment particles and compares efficiency among labware.

As previously mentioned, the *k*-factor of a rotor is determinant upon the pathlength (r_{max}/r_{min}) of the standard tube for the specified rotor. If a researcher is restricted to a specific rotor geometry and maximum *g*-force, improvements to *k*-factor can still be achieved by decreasing pathlength. One such example is the use of Beckman Coulter, Inc. *g*-Max tubes. This innovative system uses patented Beckman Coulter Quick-Seal bell-top polyallomer tubes and floating spacers. Unlike conventional sleeve-type adapters, the *g*-Max spacers "float" on top of the tube and the sample is kept at the maximum radius of the tube cavity—shortening the pathlength of the standard tube for the specified rotor—allowing you to run smaller volumes of samples without a reduction in *g*-force. In rotors where *g*-Max tubes correspond to a shorter pathlength and smaller *k*-factor, the run duration can be reduced, saving critical time in researchers' lives. *g*-Max tubes are compatible with most Beckman Coulter ultracentrifuge rotors.

In Figure 1, the *g*-Max technology exhibits the large amounts of time researchers can save by utilizing different labware. In the Type 90 Ti rotor, the *k*-factor of a 4.2 mL *g*-Max tube is 11 compared to a 13.5 mL tube with a *k*-factor of 25, both spun at 90,000 rpm. Figure 1 illustrates an example where *g*-Max technology results in a 56% savings in time between the two tubes. In many applications,

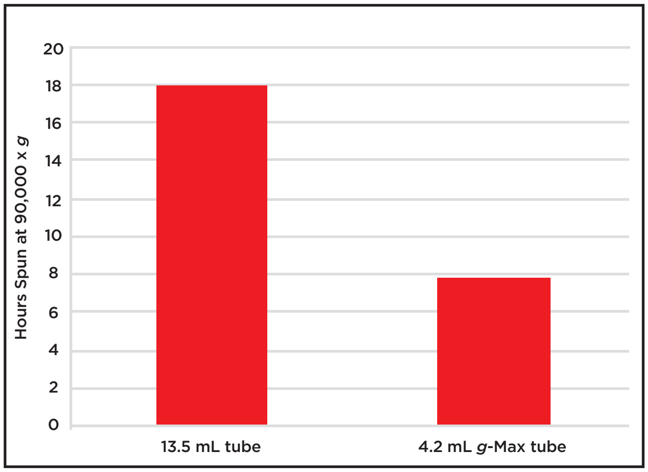

Figure 1. Comparative efficiency of *g*-Max technology.

an overnight spin of 18 hours is required. However, with the *g*-Max tube, equivalent separations are achieved in less than 8 hours, better fitting within a typical workday and generating a more convenient workflow.

k-Factors and Large-Scale Vaccine Production

k-factors affect the pelleting time of all types of centrifuges, not just ultracentrifuges as previously discussed. The following example will illuminate how *k*-factor affects rotor efficiency in high-performance centrifuges.

Large-scale production of vaccines is critical to the human race in order to combat widespread plagues and eradicate illnesses throughout the world. In many cases, cells are harvested by high-capacity centrifugation at speeds of around 5,000 x *g*. Traditionally, this application has been performed in swinging bucket rotors; however, high-throughput is most critical to researchers in the field to increase yield and shorten the time to market. Table 2 demonstrates that Beckman Coulter, Inc. rotors, J-LITE JLA-8.1000 and J-LITE JLA-9.1000, are well-designed and minimize the *k*-factor while processing large volumes in a single spin. This saves valuable lab time, rotor wear, and electricity costs, since low *k*-factors correspond to high-efficiency. Furthermore, during vaccine production, after the initial cell pelleting step, purification of the pathogenic virus antigens requires speeds in excess of 15,000 x *g*—a capability ubiquitous in both of the Beckman Coulter 1-liter high-capacity rotors, adding functionality to already efficient rotors. Beckman Coulter provides manufacturers the ability to improve process performance, reduce costs, and shorten time to market.

Table 2. Comparison of High-Capacity Fixed Angle 1-Liter Rotors.

Rotor	J-LITE JLA-8.1000	J-LITE JLA-9.1000	Fiberlite™ F9-6 x 1,000 LEX	Fiberlite F8-6 x 1,000y	Fiberlite F5-10 x 1,000 LEX	Fiberlite F6-6 x 1,000y
Type	Fixed-Angle	Fixed-Angle	Fixed-Angle	Fixed-Angle	Fixed-Angle	Fixed-Angle
Maximum volume (mL)	6x1,000	4x1,000	6x1,000	6x1,000	10x1,000	6x1,000
Maximum speed (rpm)	8,000	9,000	9,000	8,500	5,500	6,000
Minimum radius (mm)	119	82	65	54	124	54
Maximum radius (mm)	222.8	185	194	196	275	196
Maximum *g*-force	15,970 x *g*	16,800 x *g*	17,568 x *g*	15,900 x *g*	9,333 x *g*	7,900 x *g*
Total pathlength (mm)	103.8	103	129	142	151	142
k-factor with largest volume at max speed	2,482	2,540	3,415	5,096	6,662	9,060

Table 3. Preparative Ultracentrifuge Rotors and Corresponding *k*-Factors.

Rotor	Max Speed (rpm)	Max RCF (*g*-force)	Rotor Places x Volume (mL)	*k*-Factor with Largest Volume Tube at Max Speed	*k*-Factor with *g*-Max Tube	Volume of *g*-Max Tube (mL)
Fixed-Angle Rotors						
Type 100 Ti	100,000	802,400	8x6.8	15	7	2
Type 90 Ti	90,000	694,000	8x13.5	25	11	4.2
Type 70.1 Ti	70,000	450,000	12x13.5	36	17	4.2
Type 70 Ti	70,000	504,000	8x39	44	24	15
Type 50.2 Ti	50,000	302,000	12x39	62	39	15
Type 45 Ti	45,000	235,000	6x94	133	—	—
Type 50.4 Ti	50,000	270,000	44x6.5	39	15	2
Type 42.2	42,000	223,000	72x0.230	9	—	—
Type 25	25,000	92,500	100x1	62	—	—
Type 19	19,000	53,900	6x250	951	—	—
Near-Vertical & Vertical Tube Rotors						
NVT 100	100,000	750,000	13x51	8	6	2
NVT 90	90,000	645,000	8x5.1	10	7	2
NVT 65.2	65,000	416,000	16x5.1	15	7	2
NVT 65	65,000	402,000	8x13.5	21	8	6.3
VTi 90	90,000	645,000	8x5.1	6	6	3.5
VTi 65.1	65,000	402,000	8x13.5	13	13	6.3
VTi 50	50,000	242,000	8x39	36	36	15
VTi 65.2	65,000	416,000	16x5.1	10	10	2
Swinging Bucket Rotors						
SW 60 Ti	60,000	485,000	6x4	45	24	1.5
SW 55 Ti	55,000	368,000	6x5	48	29	2
SW 41 Ti	41,000	288,000	6x13.2	124	27	3.5
SW 40 Ti	40,000	285,000	6x14	137	35	3.5
SW 32 Ti	32,000	175,000	6x38.5	204	74	8.4
SW 32.1 Ti	32,000	187,000	6x17	229	56	4.5
SW 28	28,000	141,000	6x38.5	246	87	15
SW 28.1	28,000	150,000	6x17	276	67	4.2

Table 4. Micro-Ultracentrifuge Rotors and Corresponding *k*-Factors.

Rotor	Max Speed (rpm)	Max RCF (*g*-force)	Rotor Places x Volume (mL)	*k*-Factor with Largest Volume Tube at Max Speed	*k*-Factor with *g*-Max Tube	Volume of *g*-Max Tube (mL)
Fixed-Angle Rotors						
TLA-120.1	120,000	627,000	14x0.5	8	—	—
TLA-120.2	120,000	627,000	10x2.0	16	14	1.5
TLA-110	110,000	657,000	8x5.1	13	5	2.0
TLA-100	100,000	436,000	20x0.2	7	—	—
TLA-100.3	100,000	541,000	6x3.5	14	11	2.0
TLA-55	55,000	186,000	12x1.5	66	—	—
MLA-150	150,000	1,003,000	8x2.0	10.4	6.2	1.5
MLA-130	130,000	1,019,000	10x2.0	8.7	7	1.5
MLA-80	80,000	444,000	8x8.0	29	18	4.2
MLA-55	55,000	287,000	8x13.5	53	28	4.2
MLA-50	50,000	233,000	6x32.4	92	50	15
Near-Vertical & Vertical Tube Rotors						
TLN-120	120,000	585,000	8x1.2	7	—	—
TLN-100	100,000	450,000	8x3.9	14	—	—
MLN-80	80,000	389,000	8x8.0	20	16	4.2
Swinging Bucket Rotors						
TLS-55	55,000	259,000	4x2.2	50	37	1.5
MLS-50	50,000	268,000	4x5.0	71	29	2.0

Table 5. High-Performance Rotors and Corresponding *k*-Factors.

Rotor	Max Speed (rpm)	Max RCF (*g*-force)	Rotor Places x Volume (mL)	*k*-Factor with Largest Volume Tube at Max Speed
Fixed-Angle Rotors				
JA-30.50 Ti	30,000	108,860	8x50	280
JA-25.50	25,000	75,600	8x50	418
JA-25.15	25,000	Outer Row: 74,200 Inner Row: 60,200	24x15	Outer Row: 265 Inner Row: 380
JA-21	21,000	50,400	18x10	470
JA-20.1	20,000	Outer Row: 51,500 Inner Row: 43,900	32x15	Outer Row: 371 Inner Row: 465
JA-20	20,000	48,400	8x50	769
JA-18.1	18,000	42,100	24x1.8	156
JA-18	18,000	47,900	10x100	566
JA-17	17,000	39,800	14x50	690
J-LITE JLA-16.250	16,000	38,400	6x250	1,090
JA-14.50	14,000	35,000	16x50	787
JA-14	14,000	30,100	6x250	1,764
JA-12	12,000	23,200	12x50	1,244
J-LITE JLA-10.500	10,000	18,600	6x500	2,850
JA-10	10,000	17,700	6x500	3,610
J-LITE JLA-9.1000	9,000	16,800	4x1,000	2,544
J-LITE JLA-8.1000	8,000	15,970	6x1,000	2,482
Swinging Bucket Rotors				
JS-24.15	24,000	110,500	6x15	376
JS-24.38	24,000	103,900	6x38.5	334
JS-13.1	13,000	26,500	6x50	1,841
JS-7.5	7,500	10,400	4x250	5,287
JS-5.9	5,900	6,570	—	—
JS-5.3	5,300	Conical Bottles: 6,870 Deep-Well Plates: 6,130	4x500	Conical Bottles: 7,728 Deep-Well Plates: 1,536
JS-5.0	5,000	7,480	4x2,250	9,171
JS-4.3	4,300	4,220	4x750	11,800
JS-4.2	4,200	5,020	6x1,000	11,500
JS-4.0	4,000	4,050	4x1,000	15,300

Please see rotor manuals for a complete listing of available tube sizes and for any additional information.
For additional rotor calculation information, visit www.beckmancoulter.com

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