Chemical Product Design

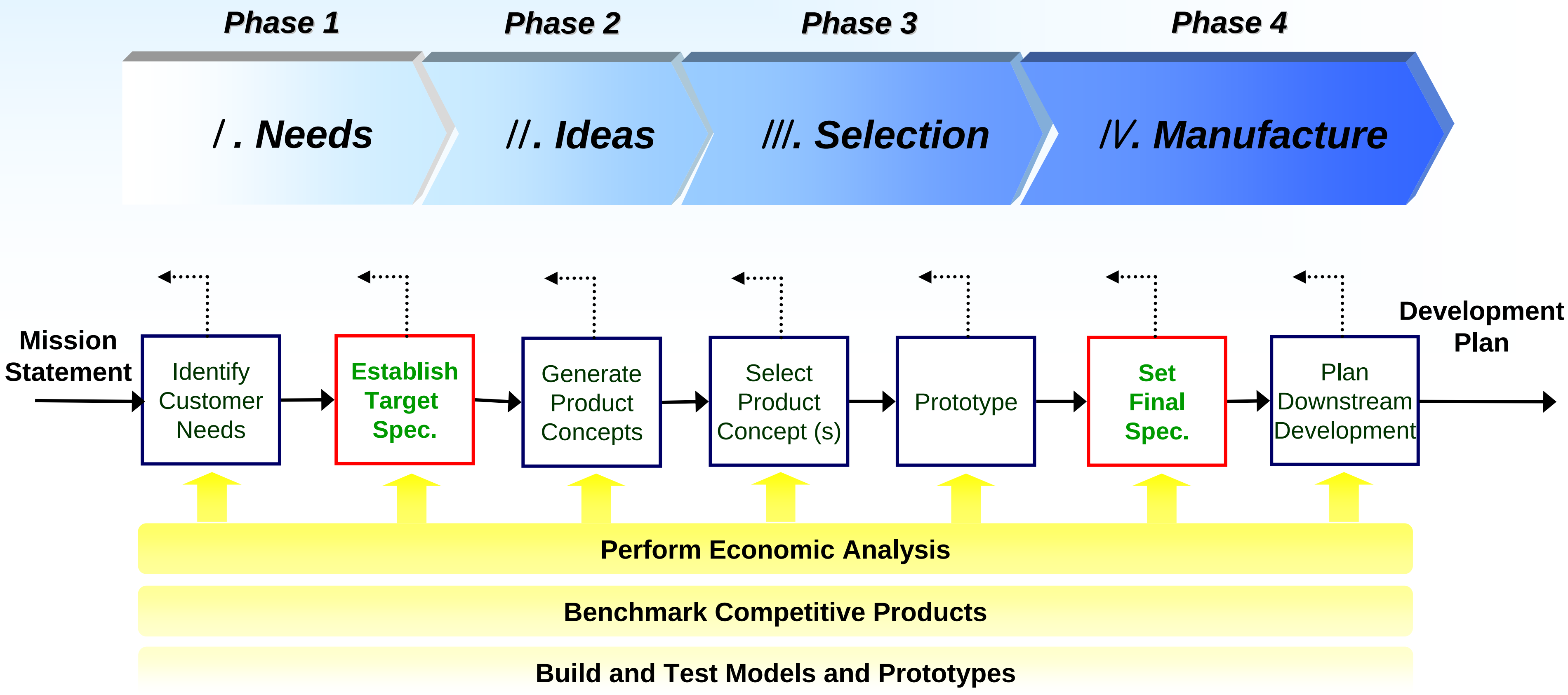
Sungwoo Cho and Chonghun Han
Intelligent Process Systems Laboratory
School of Chemical and Biological Engineering
Seoul National University

PART V. Product Specifications

- Set Target Specifications
- Refine Specifications
- Reflect on the Results and the Process

Procedure

Phase 2. Product Specifications



Product Specifications Process

1. **Set Target Specifications**

   - Based on customer needs and benchmarks

   - Develop metrics for each need

   - Set ideal and acceptable values

2. **Refine Specifications**

   - Based on selected concept and feasibility testing

   - Technical modeling

   - Trade-offs are critical

3. **Reflect on the Results and the Process**

   - Critical for ongoing improvement

Based on Customer Needs and Benchmarks

Example – Mountain Bike Suspension Fork

Based on Customer Needs and Benchmarks

#	Need	Importance
1	**The suspension reduces vibration to the hands.**	**3**
2	**The suspension allows easy traversal of slow, difficult terrain.**	**2**
3	**The suspension enables high speed descents on bumpy trails.**	**5**
4	**The suspension allows sensitivity adjustment.**	**3**
5	**The suspension preserves the steering characteristics of the bike.**	**4**
6	**The suspension remains rigid during hard concerning.**	**4**
7	**The suspension is lightweight.**	**4**
8	**The suspension provides stiff mounting points for the brakes.**	**2**
9	**The suspension fits a wide variety of bikes, wheels, and tires.**	**5**
10	**The suspension is easy to install.**	**1**
11	**The suspension works with fenders.**	**1**
12	**The suspension instills pride.**	**5**
13	**The suspension is affordable for an amateur enthusiast.**	**5**
14	**The suspension is not contaminated by water.**	**5**
15	**The suspension is not contaminated by grunge.**	**5**
16	**The suspension can be easily accessed for maintenance.**	**3**
17	**The suspension allows easy replacement of worn parts.**	**1**
18	**The suspension can be maintained with readily available tools.**	**3**
19	**The suspension lasts a long time.**	**5**
20	**The suspension is safe in a crash.**	**5**

Establish Product Specifications and Units

Metric No.	Need Nos.	Metric	Importance	Units
1	1, 3	**Attenuation from dropout to handlebar at 10 Hz**	3	**dB**
2	2, 6	**Spring preload**	3	**N**
3	1, 3	**Maximum value from the Monster**	5	**g**
4	1, 3	**Minimum descent time on test track**	5	**s**
5	4	**Damping coefficient adjustment range**	3	**N-s/m**
6	5	**Maximum travel (26-in. wheel)**	3	**mm**
7	5	**Rake offset**	3	**mm**
8	6	**Lateral stiffness at brake pivots**	3	**kN/m**
9	7	**Total mass**	4	**kg**
10	8	**Lateral stiffness at brake pivots**	2	**kN/m**
11	9	**Headset sizes**	5	**in.**
12	9	**Steertube length**	5	**mm**
13	9	**Wheel sizes**	5	**List**
14	9	**Maximum tire width**	5	**in.**
15	10	**Time to assemble to frame**	1	**s**
16	11	**Fender compatibility**	1	**List**
17	12	**Instills pride**	5	**Subj.**
18	13	**Unit manufacturing cost**	5	**US $**
19	14	**Time in spray chamber without water entry**	5	**s**
20	15	**Cycles in mud chamber without contamination**	5	**k-cycles**
21	16, 17	**Time to disassemble / assemble for maintenance**	3	**s**
22	17, 18	**Special tools required for maintenance**	3	**List**
23	19	**UV test duration to degrade**	5	**hr**
24	19	**Monster cycles to failure**	5	**Cycles**
25	20	**Bending strength (frontal loading)**	5	**Binary**

Benchmark on Customer Needs

#	Need	Imp	ST Tritrack	Maniary 2	Rox Tahx Quadra	Rox Tahx Ti 21	Tonka Pro	Gunhill Head Shox
1	**The suspension reduces vibration to the hands.**	3	♦	♦♦♦♦	♦♦	♦♦♦♦♦	♦♦	♦♦♦
2	**The suspension allows easy traversal of slow, difficult terrain.**	2	♦♦	♦♦♦♦	♦♦♦	♦♦♦♦♦	♦♦♦	♦♦♦♦♦
3	**The suspension enables high speed descents on bumpy trails.**	5	♦	♦♦♦♦♦	♦♦	♦♦♦♦♦	♦♦	♦♦♦
4	**The suspension allows sensitivity adjustment.**	3	♦	♦♦♦♦	♦♦	♦♦♦♦♦	♦♦	♦♦♦
5	**The suspension preserves the steering characteristics of the bike.**	4	♦♦♦♦	♦♦	♦	♦♦	♦♦♦	♦♦♦♦♦
6	**The suspension remains rigid during hard concerning.**	4	♦	♦♦♦	♦	♦♦♦	♦	♦♦♦♦♦
7	**The suspension is lightweight.**	4	♦	♦♦♦	♦	♦♦♦♦♦	♦♦♦♦	♦♦♦♦♦
8	**The suspension provides stiff mounting points for the brakes.**	2	♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦	♦♦♦♦♦
9	**The suspension fits a wide variety of bikes, wheels, and tires.**	5	♦♦♦♦	♦♦♦♦♦	♦♦♦	♦	♦♦♦	♦
10	**The suspension is easy to install**	1	♦♦♦♦	♦♦♦♦♦	♦♦♦♦	♦♦♦♦♦	♦♦♦♦♦	♦
11	**The suspension works with fenders.**	1	♦♦♦	♦	♦	♦	♦	♦♦♦♦♦
12	**The suspension instills pride.**	5	♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦	♦♦♦♦♦
13	**The suspension is affordable for an amateur enthusiast.**	5	♦♦♦♦♦	♦	♦♦♦	♦	♦♦♦	♦♦
14	**The suspension is not contaminated by water.**	5	♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦	♦♦♦♦♦
15	**The suspension is not contaminated by grunge.**	5	♦	♦♦♦	♦	♦♦♦♦	♦♦	♦♦♦♦♦
16	**The suspension can be easily accessed for maintenance.**	3	♦♦♦♦	♦♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦♦	♦
17	**The suspension allows easy replacement of worn parts.**	1	♦♦♦♦	♦♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦♦	♦
18	**The suspension can be maintained with readily available tools.**	3	♦♦♦♦♦	♦♦♦♦♦	♦♦♦♦♦	♦♦♦♦♦	♦♦	♦
19	**The suspension lasts a long time.**	5	♦♦♦♦♦	♦♦♦♦♦	♦♦♦♦♦	♦♦♦	♦♦♦♦♦	♦
20	**The suspension is safe in a crash.**	5	♦♦♦♦♦	♦♦♦♦♦	♦♦♦♦♦	♦♦♦♦♦	♦♦♦♦♦	♦♦♦♦♦

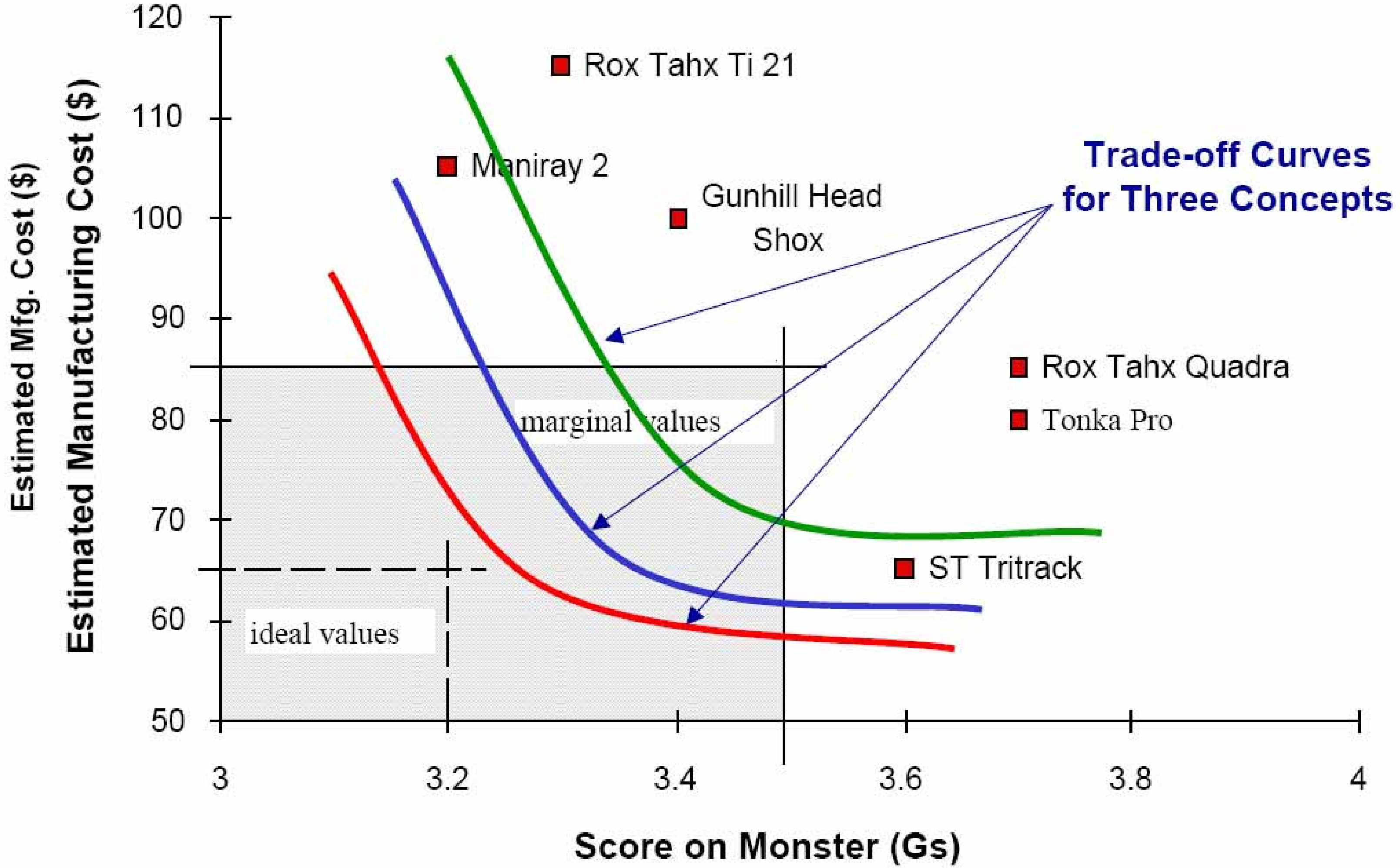
Benchmark on Metrics

Metric #	Needs #s	Metric	Imp	Units	ST Tritrack	Maniary 2	Rox Tahx Quadra	Rox Tahx Ti 21	Tonka Pro	Gunhill Head Shox
1	1, 3	Attenuation from dropout to handlebar at 10 Hz	3	dB	8	15	10	15	9	13
2	2, 6	Spring pre-load	3	N	550	760	500	710	480	680
3	1, 3	Maximum value from the Monster	5	g	3.6	3.2	3.7	3.3	3.7	3.4
4	1, 3	Minimum descent time on test track	5	s	13	11.3	12.6	11.2	13.2	11
5	4	Damping coefficient adjustment range	3	N-s/m	0	0	0	200	0	0
6	5	Maximum travel (26 in wheel)	3	mm	28	48	43	46	33	38
7	5	Rake offset	3	mm	41.5	39	38	38	43.2	39
8	6	Lateral stiffness at the tip	3	kN/m	59	110	85	85	65	130
9	7	Total mass	4	kg	1.409	1.385	1.409	1.364	1.222	1.1
10	8	Lateral stiffness at brake pivots	2	kN/m	295	550	425	425	325	650
11	9	Headset sizes	5	in	1.000 1.125	1.000 1.125 1.250	1.000 1.125	1.000 1.125 1.250	1.000 1.125	NA
12	9	Steertube length	5	mm	150 180 210 230 255	140 165 190 215	150 170 190 210	150 170 190 210 230	150 190 210 220	NA
13	9	Wheel sizes	5	list	26 in	26 in	26 in	26 in 700 C	26 in	26 in
14	9	Maximum tire width	5	in	1.5	1.75	1.5	1.75	1.5	1.5
15	10	Time to assemble to frame	1	s	35	35	45	45	35	85
16	11	Fender compatibility	1	list	Zefal	none	none	none	none	all
17	12	Instills pride	5	subj	1	4	3	5	3	5
18	13	Unit manufacturing cost	5	US$	65	105	85	115	80	100
19	14	Time in spray chamber w/o water entry	5	s	1300	2900	> 3600	> 3600	2300	> 3600
20	15	Cycles in mud chamber w/o contamination	5	k-cycles	15	19	15	25	18	35
21	16, 17	Time to disassemble/assemble for maintenance	3	s	160	245	215	245	200	425
22	17, 18	Special tools required maintenance	3	list	hex	hex	hex	hex	long hex	hex, pin wranch
23	19	UV test duration to degrade rubber parts	5	hours	400 +	250	400 +	400 +	400 +	250
24	19	Monster cycles to failure	5	cycles	500k +	500k +	500k +	480k +	500k +	330k +
25	20	Bending strength (frontal loading)	5	binary	pass	pass	pass	pass	pass	pass

Benchmark on Metrics

Metric No.	Metric	Units	Marginal Value	Ideal Value
1	**Attenuation from dropout to handlebar at 10 Hz**	dB	> 10	> 15
2	**Spring preload**	N	480 - 800	650 – 700
3	**Maximum value from the Monster**	g	< 3.5	< 3.2
4	**Minimum descent time on test track**	s	< 13.0	< 11.0
5	**Damping coefficient adjustment range**	N-s/m	0	> 200
6	**Maximum travel (26-in. wheel)**	mm	33 - 50	45
7	**Rake offset**	mm	37 -45	38
8	**Lateral stiffness at brake pivots**	kN/m	> 65	> 130
9	**Total mass**	kg	< 1.4	< 1.1
10	**Lateral stiffness at brake pivots**	kN/m	> 325	> 650
11	**Headset sizes**	in.	1.000 1.125	1.000 1.125 1.250
12	**Steertube length**	mm	150 190 210 230	150 170 190 210 230
13	**Wheel sizes**	List	26 in	26 in 700 c
14	**Maximum tire width**	in.	> 1.5	> 1.75
15	**Time to assemble to frame**	s	< 60	< 35
16	**Fender compatibility**	List	none	all
17	**Instills pride**	Subj.	> 3	> 5
18	**Unit manufacturing cost**	US $	< 85	< 65
19	**Time in spray chamber without water entry**	s	> 2300	> 3600
20	**Cycles in mud chamber without contamination**	k-cycles	> 15	> 35
21	**Time to disassemble / assemble for maintenance**	s	< 300	< 160
22	**Special tools required for maintenance**	List	hex	hex
23	**UV test duration to degrade**	hr	> 250	> 450
24	**Monster cycles to failure**	Cycles	> 300k	> 500k
25	**Bending strength (frontal loading)**	Binary	pass	pass

Specifications Trade-offs



Set Final Specifications

Metric No.	Metric	Units	Value
1	**Attenuation from dropout to handlebar at 10 Hz**	dB	> 12
2	**Spring preload**	N	650
3	**Maximum value from the Monster**	g	< 3.4
4	**Minimum descent time on test track**	s	< 11.5
5	**Damping coefficient adjustment range**	N-s/m	> 100
6	**Maximum travel (26-in. wheel)**	mm	43
7	**Rake offset**	mm	38
8	**Lateral stiffness at brake pivots**	kN/m	> 75
9	**Total mass**	kg	< 1.4
10	**Lateral stiffness at brake pivots**	kN/m	> 425
11	**Headset sizes**	in.	1.000 1.125
12	**Steertube length**	mm	150 170 190 210 230
13	**Wheel sizes**	List	26 in
14	**Maximum tire width**	in.	> 1.75
15	**Time to assemble to frame**	s	< 45
16	**Fender compatibility**	List	Zefal
17	**Instills pride**	Subj.	> 4
18	**Unit manufacturing cost**	US $	< 80
19	**Time in spray chamber without water entry**	s	> 3600
20	**Cycles in mud chamber without contamination**	k-cycles	> 25
21	**Time to disassemble / assemble for maintenance**	s	< 200
22	**Special tools required for maintenance**	List	hex
23	**UV test duration to degrade**	hr	> 450
24	**Monster cycles to failure**	Cycles	> 500k
25	**Bending strength (frontal loading)**	Binary	pass

Chemical Industry Example

Product Specifications = Rheological Properties

Source: Wibowo, Christianto and Ng Ka M. "Product-Oriented Process Synthesis and Development: Creams and Pastes", AIChE Journal vol.47, no. 12, December 2001.

Property and Models		*Term for Behavior*	*Description*	*Parameter Values*
Viscosity		Newtonian	Viscosity is constant irrespective of shear rate	$n=1,\ \tau_0=0,\ t_r=0$
$\mu_\infty = \frac{\tau_0}{\dot{\gamma}} + K\dot{\gamma}^{n-1}$	(1)			
		Pseudoplastic (shear-thinning)	Viscosity decreases with increasing shear rate	$n<1$
$\mu = \mu_\infty + (\mu_0 - \mu_\infty)\left\{1 - \exp\left[-\left(\frac{t}{t_r}\right)^a\right]\right\}$	(2)	Dilatant (shear-thickening)	Vicosity increases with increasing shear rate	$n>1$
		Plastic	Exhibits a critical stress (yield value) below which flow does not occur	$\tau_0 > 0$
		Thixotropic	Viscosity decreases during shearing, and gradually increases to its original value after shearing stops	$n<1,\ t_r>0$
		Rheopective	Viscosity increases during shearing, and gradually decreases to its original value after shearing stops	$n>1,\ t_r>0$
Complex Modulus		Viscous	Energy is fully lost when the material is deformed under an external force	$G'=0,\ G''=\omega\mu$ $N_{De}=0$
$G^* = G' + iG''$	(3)			
		Elastic	Energy is fully stored when the material is deformed under an extranal force, and released when the force is relaxed	$G'=G,\ G''=0$ $N_{De}=\infty$
$N_{De} = \frac{G'}{G''}$	(4)	Viscoelastic	Combination of elastic and viscous properties	$G'\neq 0,\ G''\neq 0$ $0<N_{De}<\infty$

Chemical Industry Example

Product Specifications = Heuristics

Source: Wibowo, Christianto and Ng Ka M. "Product-Oriented Process Synthesis and Development: Creams and Pastes", AIChE Journal vol.47, no. 12, December 2001.

We need to quantify the relationship between flow properties and sensorial attributes described in qualitative terms such as "spreadable", "sticky", "creamy" and so on.

- Prefer a product with thixotropic behavior to deliver highly viscous product as a thinner material
- Prefer a product showing shear-thinning behavior if the product should be thick at rest but spread easily upon shearing
- Prefer a semi-solid or highly viscous product to avoid phase separation and to increase product stability
- Aim for a maximum viscosity of 120-500 Pa·s for lotions (liquid-like creams) and 1,350-3,500 Pa·s for solid-like creams to obtain the best acceptance
- In making a product to be applied to the skin, aim for a viscosity of about 0.025 Pa·s at the application shear rate to obtain the best acceptance