Chemical Engineering Fundamentals and Design

Lecture 02

Review on Solving Engineering Problems (Acid-Neutralization)

Strategies for solving problems

Steps to solving problems

1. Define the problem.
2. List possible solutions.
3. Evaluate and rank the possible solutions.
4. Develop a detailed plan for the most attractive solution(s).
5. Re-evaluate the plan to check desirability.
6. Implement the plan.
7. Check the results.

Strategies for solving problems

Ethical considerations in solving problems

- **Code of ethics** (http://www.aiche.org/about/code-ethics)
- **Safety**
- **Protecting the environment**
- **Avoiding harassment**
- **Ethical practice**

Strategies for solving problems

Memo from supervisor (Chapter 01 in Introduction to Chemical Engineering):

ABC Chemical Company
Memorandum

From: Barbara Magelby, Supervisor, Chemical Process Group

We’ve just received information indicating that the company that has been disposing of our HCl byproduct is not doing well. We anticipate that they will be going out of business in 6-12 months. This puts us in a very dangerous situation, since we can’t operate very long without disposing of that waste. Our marketing people have tried to find a potential buyer for the acid, but the byproduct is apparently not at an appropriate concentration or purity to be valuable to anyone in our local area.

One possibility to consider is treatment of the waste in order to be able to dispose of it in the lake next to our company site. However, at this point, no engineering analysis has been conducted on this or any other strategy.

Your assignment is to propose a strategy and design (with a cost analysis) for safely and legally disposing of the acid waste.

Please keep me informed of your progress.

Strategies for solving problems

1. Define the problem:

a. Many problems have taken longer than necessary to solve because they were not defined correctly.

b. For our problem, we are looking for a way to continue viable operation of our process without depending on the company that has been disposing of our acid waste.

c. From our company records,

average acid stream flow rate: 11,600 L/hr

average HCl concentration in the waste stream: 0.014 M

Strategies for solving problems

2. List possible solutions

a. Change our company process so that the acid is not produced.

b. Contract with another independent company to take the acid away.

c. Build giant holding tanks to store the acid for 10 years.

d. Discharge the acid to an evaporation pond built on the company site.

e. Discharge the acid into the lake next to the company site without treatment.

f. Treat the acid and discharge it into the lake.

Strategies for solving problems

3. Evaluate and rank the possible solutions:

a. Change our company process so that the acid is not produced.

: Alternative processes are usually not known or are extremely expansive.

b. Contract with another independent company to take the acid away.

: Transportation costs and profit for the independent company would be added.

: It would seem that we can do it more cheaply.

: No such company is presented in this analysis.

Strategies for solving problems

3. Evaluate and rank the possible solutions:

c. Build giant holding tanks to store the acid for 10 years.

: The required volume of such tanks would be

$$11600\ L/hr \times \frac{24\ hr}{1\ day} \times \frac{365\ days}{1\ yr} \times 10\ yrs = 1.0 \times 10^{9}\ L$$

: The volume occupied by each tank (10 m in diameter and 5 m in height) would be

$$Volume = \frac{\pi}{4} D^{2} H = \frac{\pi}{4} (10\ m)^{2} (5\ m) = 393\ m^{3} = 393 \times 10^{3}\ L$$

: The 2587 tanks would be needed (a cost for building and maintaining).

: Not a sustainable solution and not suitable from an environmental perspective

Strategies for solving problems

3. Evaluate and rank the possible solutions:

d. Discharge the acid to an evaporation pond built on the company site.

: Need to construct the ponds making sure that no acid leaked into the ground water.

: Land would have to be available.

: Consider the average evaporation rate (> 11600 L/hr).

: Ensure that the amount of acid in evaporating water is smaller than limits.

: Dispose of the concentrated acid left as a result of the evaporation process

Strategies for solving problems

3. Evaluate and rank the possible solutions:

e. Discharge the acid into the lake next to the company site without treatment.

: Environmental responsibility

: Violation against the environmental protection laws

f. Treat the acid and discharge it into the lake.

: Neutralizing the acid in the stream with a basic solution

: Cooling the treated stream before final discharging to the lake

Strategies for solving problems

4. Develop a detailed plan for the most attractive solution(s):

Let’s suppose that…

1) a preliminary analysis suggests that option (f) is the best option.

2) you have selected the strategy of neutralizing the acid by addition of sodium hydroxide to the waste stream.

$$\mathbf{HCl + NaOH \rightarrow H_2O + NaCl}$$

If the upper limit for dissolved solids in water is 1200 mg/L (= 1.2 g/L),

$$\frac{1.2\ g / L}{58.5\ g / gmol} = 0.02\ gmol / L > 0.014\ gmol / L$$

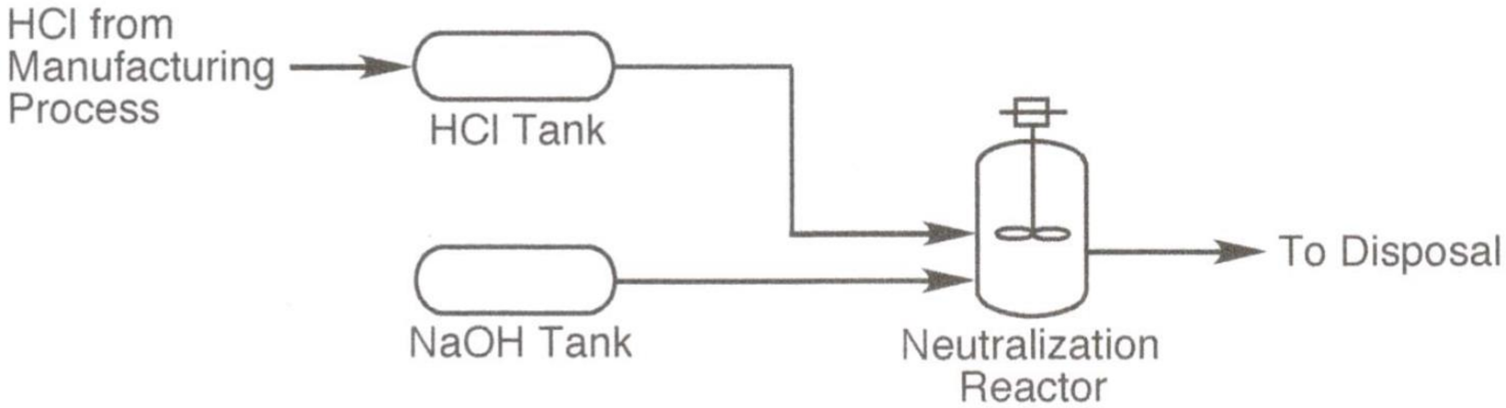
(The final concentration cannot exceed.)

Obviously, there is much more detail needed for the design of the acid-neutralization process.

Strategies for solving problems

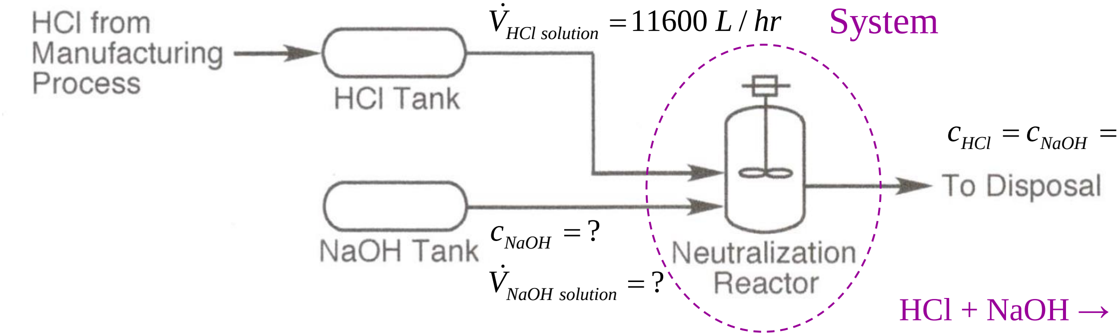
4. Develop a detailed plan for the most attractive solution(s):

Process flow diagram (PFD) for acid neutralization concept



Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 05. Material Balance)



$c_{HCl} = 0.014\ M$

$\dot{V}_{HCl\ solution} = 11600\ L/hr$

System

$c_{NaOH} = ?$

$\dot{V}_{NaOH\ solution} = ?$

$c_{HCl} = c_{NaOH} = 0\ M$

$$\frac{r_{consumption,HCl}}{r_{consumption,NaOH}} = \frac{1}{1} = 1$$

$HCl + NaOH \longrightarrow H_2O + NaCl$

Steady-State Mole Balance for HCl

$$\sum_{\substack{input\\streams}} \left(c_{HCl}\dot{V}_{HCl\ solution}\right)_{in} + \cancelto{0}{r_{formation,HCl}} = \sum_{\substack{output\\streams}} \cancelto{0}{\left(c_{HCl}\dot{V}_{HCl\ solution}\right)_{out}} + r_{consumption,HCl}$$

$$r_{consumption,HCl} = r_{consumption,NaOH}$$

Steady-State Mole Balance for NaOH

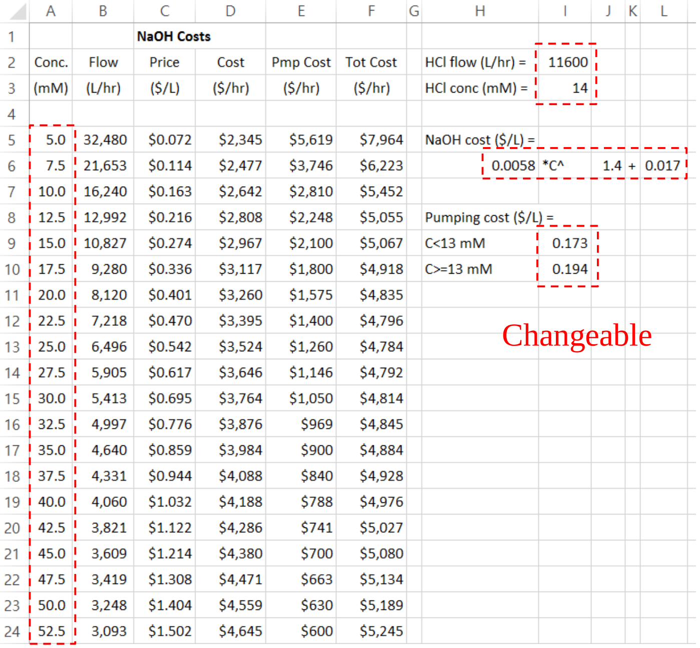
$$\sum_{\substack{input\\streams}} \left(c_{NaOH}\dot{V}_{NaOH\ solution}\right)_{in} + \cancelto{0}{r_{formation,NaOH}} = \sum_{\substack{output\\streams}} \cancelto{0}{\left(c_{NaOH}\dot{V}_{NaOH\ solution}\right)_{out}} + r_{consumption,NaOH}$$

$$\longrightarrow c_{NaOH}\dot{V}_{NaOH\ solution} = c_{HCl}\dot{V}_{HCl\ solution}$$

$$\dot{V}_{NaOH\ solution} = \frac{c_{HCl}\dot{V}_{HCl\ solution}}{c_{NaOH}}$$

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 06. Spreadsheets)



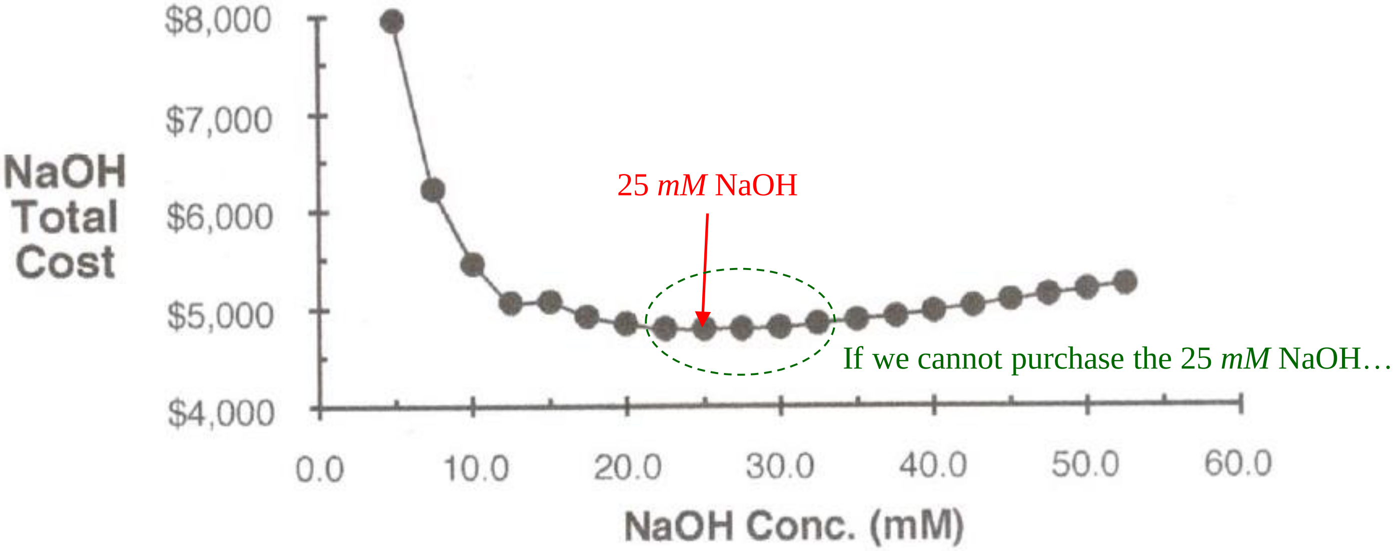
	A	B	C	D	E	F	G	H	I	J	K	L
1			**NaOH Costs**									
2	Conc.	Flow	Price	Cost	Pmp Cost	Tot Cost		HCl flow (L/hr) =	11600			
3	(mM)	(L/hr)	($/L)	($/hr)	($/hr)	($/hr)		HCl conc (mM) =	14			
4												
5	5.0	32,480	$0.072	$2,345	$5,619	$7,964		NaOH cost ($/L) =				
6	7.5	21,653	$0.114	$2,477	$3,746	$6,223		0.0058	*C^	1.4	+	0.017
7	10.0	16,240	$0.163	$2,642	$2,810	$5,452						
8	12.5	12,992	$0.216	$2,808	$2,248	$5,055		Pumping cost ($/L) =				
9	15.0	10,827	$0.274	$2,967	$2,100	$5,067		C<13 mM	0.173			
10	17.5	9,280	$0.336	$3,117	$1,800	$4,918		C>=13 mM	0.194			
11	20.0	8,120	$0.401	$3,260	$1,575	$4,835						
12	22.5	7,218	$0.470	$3,395	$1,400	$4,796						
13	25.0	6,496	$0.542	$3,524	$1,260	$4,784						
14	27.5	5,905	$0.617	$3,646	$1,146	$4,792						
15	30.0	5,413	$0.695	$3,764	$1,050	$4,814						
16	32.5	4,997	$0.776	$3,876	$969	$4,845						
17	35.0	4,640	$0.859	$3,984	$900	$4,884						
18	37.5	4,331	$0.944	$4,088	$840	$4,928						
19	40.0	4,060	$1.032	$4,188	$788	$4,976						
20	42.5	3,821	$1.122	$4,286	$741	$5,027						
21	45.0	3,609	$1.214	$4,380	$700	$5,080						
22	47.5	3,419	$1.308	$4,471	$663	$5,134						
23	50.0	3,248	$1.404	$4,559	$630	$5,189						
24	52.5	3,093	$1.502	$4,645	$600	$5,245						

Changeable

Strategies for solving problems

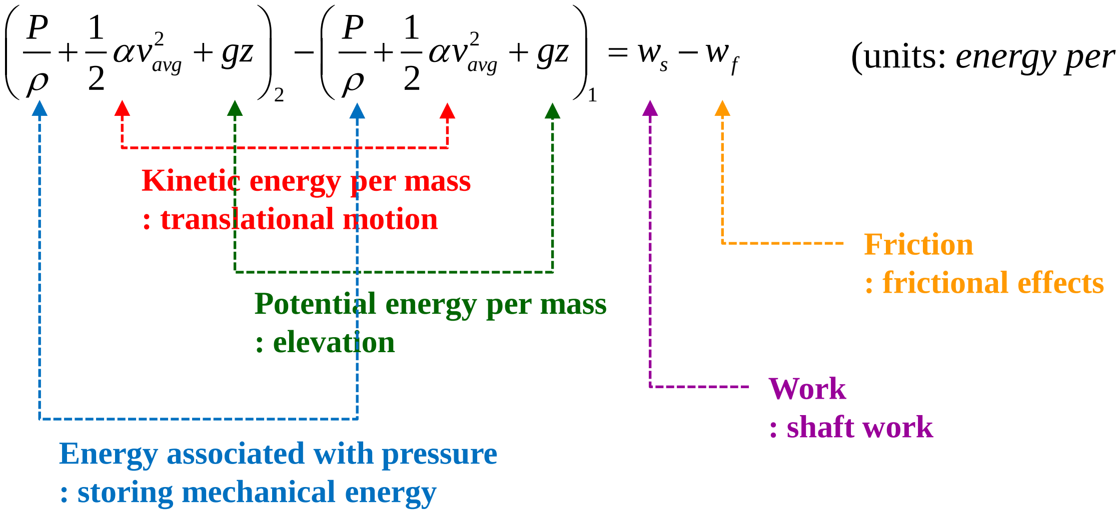
5. Re-evaluate the plane to check desirability (Chapter 06. Spreadsheets)

Chart of total cost versus NaOH concentration



Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 07. Fluid Flow)



$$\left(\frac{P}{\rho}+\frac{1}{2}\alpha v_{avg}^{2}+gz\right)_{2}-\left(\frac{P}{\rho}+\frac{1}{2}\alpha v_{avg}^{2}+gz\right)_{1}=w_{s}-w_{f}$$ (units: *energy per mass of fluid*) (7.8a)

Kinetic energy per mass
: translational motion

Potential energy per mass
: elevation

Energy associated with pressure
: storing mechanical energy

Friction
: frictional effects

Work
: shaft work

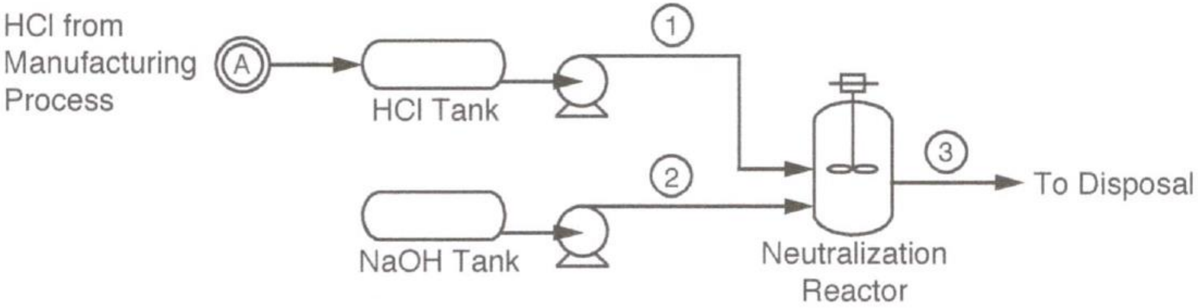
***The correction factor (α) is 2.0 for fully developed laminar pipe flow, and it ranges between 1.04 and 1.11 for fully developed turbulent flow in a circular pipe.**

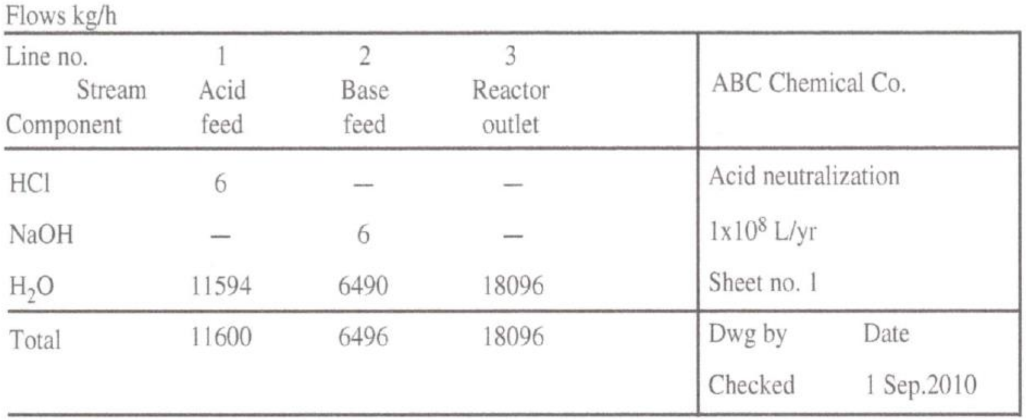
Other form: $$\frac{P_2-P_1}{\rho}+\frac{1}{2}\left(\alpha_2 v_{2,avg}^{2}-\alpha_1 v_{1,avg}^{2}\right)+g\left(z_2-z_1\right)=w_s-w_f$$ (7.8b)

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 07. Fluid Flow)

- **Process flow diagram for the acid neutralization process, including pumps**





Flows kg/h

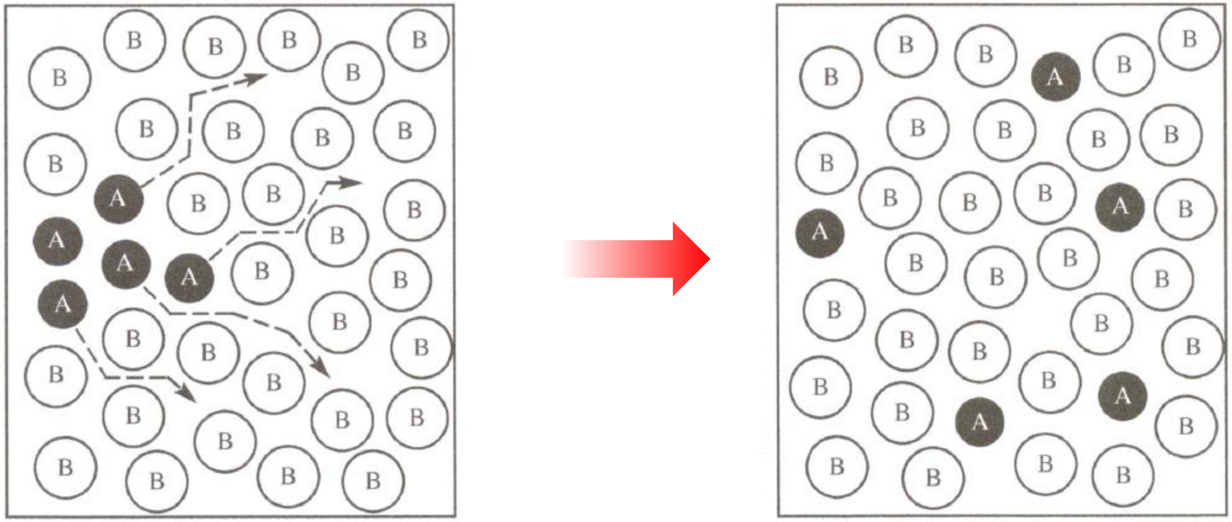
Line no. Stream Component	1 Acid feed	2 Base feed	3 Reactor outlet	ABC Chemical Co.	
HCl	6	—	—	Acid neutralization	
NaOH	—	6	—	$1x10^8$ L/yr	
H_2O	11594	6490	18096	Sheet no. 1	
Total	11600	6496	18096	Dwg by	Date
				Checked	1 Sep.2010

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 08. Mass Transfer)

- **The thermal motion of all (liquid or gas) particles at temperature above absolute zero.**
- **A function of temperature, viscosity of the fluid and the size (mass) of the particles.**

Molecular diffusion of A through B **New location of A**

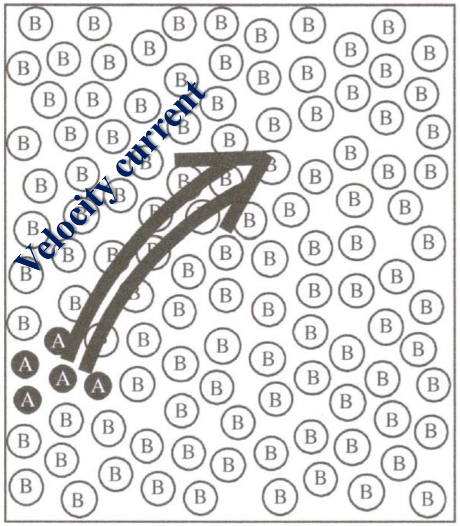


Strategies for solving problems

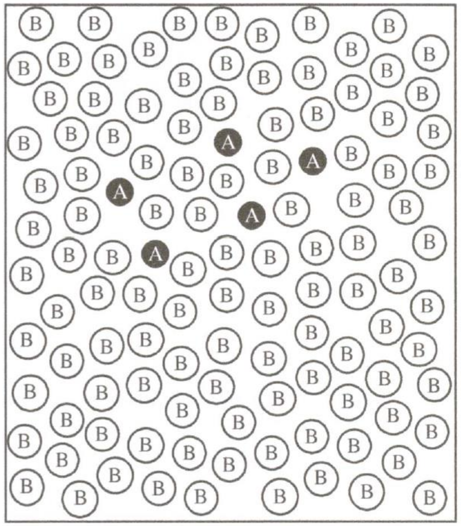
5. Re-evaluate the plane to check desirability (Chapter 08. Mass Transfer)

- **The movement of groups of molecules within fluids such as liquids or gases.**
- **Convection takes place through advection, diffusion or both.**

Mass convection of A and B



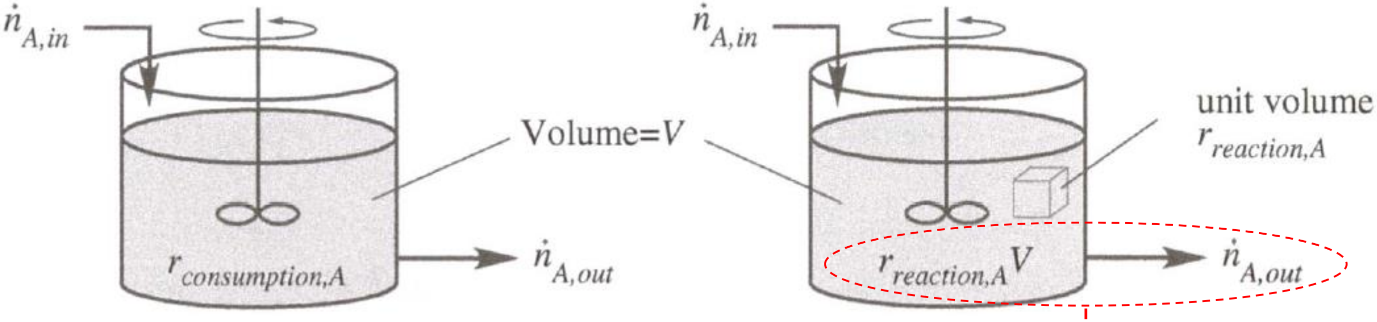
New location of A



Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 09. Reaction Engineering)

- **Irreversible reaction**
- **Continuously stirred tank reactor (CSTR)**



$$r_{consumption,A} = r_{reaction,A}V$$

$$r_{reaction,A} = k_r c_A^n c_B^m = k_r c_{A,out}^n c_{B,out}^m$$

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 09. Reaction Engineering)

Given information

$$c_{HCl_{in}} = 0.014\ gmol/L \qquad \dot{V}_{HCl_{in}} = 11,600\ L/hr$$

$$c_{NaOH_{in}} = 0.0254\ gmol/L \qquad \dot{V}_{NaOH_{in}} = 6,500\ L/hr$$

Reaction

$$HCl + NaOH \rightarrow H_2O + NaCl$$

Reaction rate constant

$$r_{reaction,HCl} = k_r c_{HCl} c_{NaOH} \qquad in\ units\ of\ moles\ of\ HCl\ or\ NaOH / (volume\ time)$$

Reaction rate constant at 25 °*C*

$$k_{r,HCl} = 1.4 \times 10^{11}\ L/gmol\ s$$

Temperature in real reactor is higher than this.

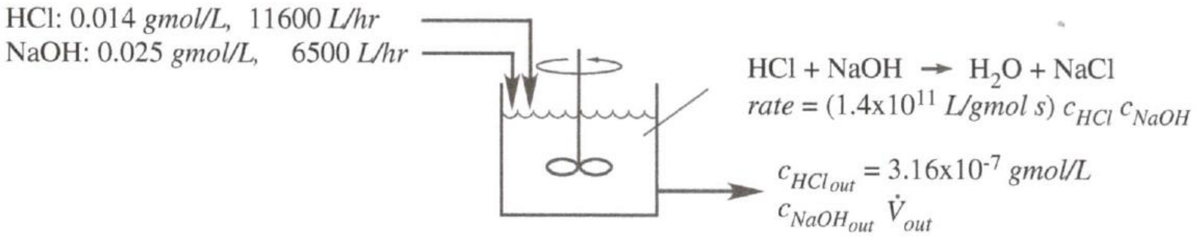
Allowed HCl concentration at final state by law (pH = 6.5)

$$c_{HCl} = 10^{-6.5} = 3.16 \times 10^{-7}\ M$$

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 09. Reaction Engineering)

Working diagram



- **Mole balance on HCl:** $c_{HCl_{in}}\dot{V}_{HCl_{in}} = c_{HCl_{out}}\dot{V}_{HCl_{out}} + r_{consumption,HCl}$
- **Mole balance on NaOH:** $c_{NaOH_{in}}\dot{V}_{NaOH_{in}} = c_{NaOH_{out}}\dot{V}_{NaOH_{out}} + r_{consumption,NaOH}$
- **Total mass balance (with constant ρ):** $\dot{V}_{HCl_{in}} + \dot{V}_{NaOH_{in}} = \dot{V}_{out}$
- **Additional relationships**

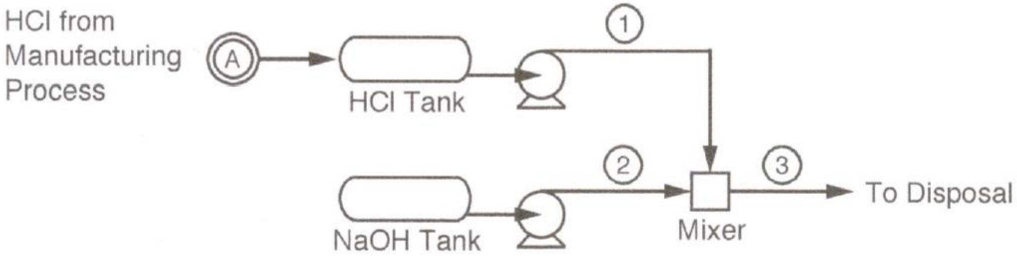
Stoichiometry: $\dfrac{r_{consumption,HCl}}{r_{consumption,NaOH}} = \dfrac{1}{1} = 1$

Molar flow rate balance: $c_{NaOH_{in}}\dot{V}_{NaOH_{in}} = c_{HCl_{in}}\dot{V}_{HCl_{in}}$

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 09. Reaction Engineering)

Process flow diagram (PFD)



Flows kg/h

Line no. Stream Component	1 Acid feed	2 Base feed	3 Mixer outlet
HCl	6	—	—
NaOH	—	6	—
H_2O	11594	6490	18096
Total	11600	6496	18096

ABC Chemical Co.

Acid neutralization

$1x10^8$ L/yr

Sheet no. 1

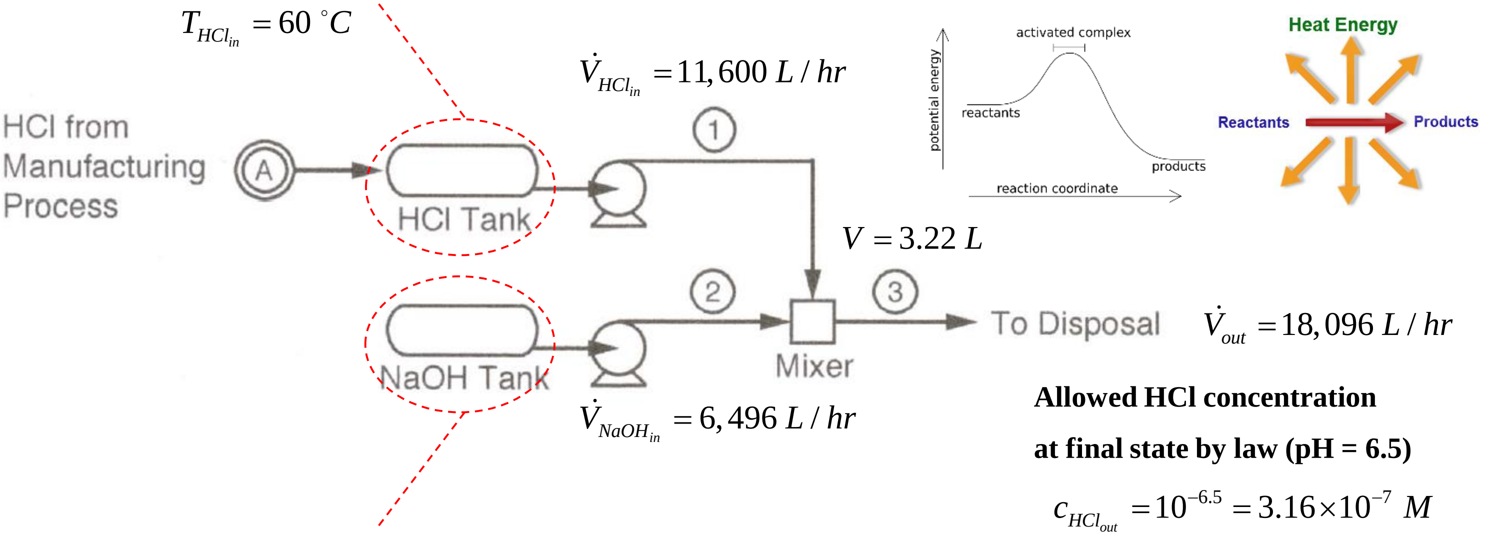
Dwg by	Date
Checked	1 Sep.2010

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 10. Heat Transfer)

$c_{HCl_{in}} = 0.014\ gmol / L$

$T_{HCl_{in}} = 60\ ^{\circ}C$



$\dot{V}_{HCl_{in}} = 11,600\ L / hr$

$V = 3.22\ L$

$\dot{V}_{out} = 18,096\ L / hr$

$\dot{V}_{NaOH_{in}} = 6,496\ L / hr$

$c_{NaOH_{in}} = 0.0254\ gmol / L$

$T_{NaOH_{in}} = 32\ ^{\circ}C$

Allowed HCl concentration

at final state by law (pH = 6.5)

$$c_{HCl_{out}} = 10^{-6.5} = 3.16\times10^{-7}\ M$$

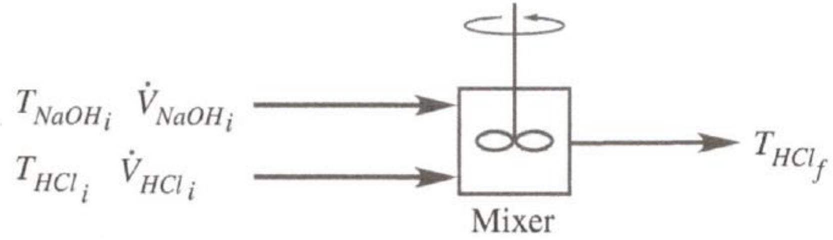
$$c_{NaOH_{out}} = c_{HCl_{out}} = 3.16\times10^{-7}\ M$$

Allowed temperature of disposal

At final state by law ($T \leq 27^{\circ}$C)

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 10. Heat Transfer)



Assumptions

1. Neglecting the heat effects from the reaction
2. Ignoring heat transfer by walls of pipes and mixer
3. Negligible kinetic and potential energies
4. No significant shaft work
5. $\rho_{water} = \rho_{HCl} = \rho_{NaOH}$, $C_{P,water} = C_{P,HCl} = C_{P,NaOH}$

$$\sum_{\substack{output\\streams}} \dot m\left[\hat H + \cancelto{0}{\frac{1}{2}\alpha v^2} + \cancelto{0}{gz}\right]_{out} - \sum_{\substack{input\\streams}} \dot m\left[\hat H + \cancelto{0}{\frac{1}{2}\alpha v^2} + \cancelto{0}{gz}\right]_{in} = \cancelto{0}{\dot Q} + \cancelto{0}{\dot W_s}$$

$$\hat H \approx \bar C_P\left(T - T_{ref}\right) \qquad \dot m = \dot V\rho$$

$$\sum_{\substack{output\\streams}} \dot m \bar C_P\left(T - T_{ref}\right) - \sum_{\substack{input\\streams}} \dot m \bar C_P\left(T - T_{ref}\right) = \left\{\dot V\rho C_P\left(T - T_{ref}\right)\right\}_f - \left\{\dot V\rho C_P\left(T - T_{ref}\right)\right\}_{HCl} - \left\{\dot V\rho C_P\left(T - T_{ref}\right)\right\}_{NaOH} = 0$$

$$\rho_{water} = \rho_{HCl} = \rho_{NaOH}, C_{P,water} = C_{P,HCl} = C_{P,NaOH}$$

$$\dot V_f = \dot V_{HCl_i} + \dot V_{NaOH_i}$$

$$T_f = \frac{\dot V_{HCl_i} T_{HCl_i} + \dot V_{NaOH_i} T_{NaOH_i}}{\dot V_{HCl_i} + \dot V_{NaOH_i}}$$

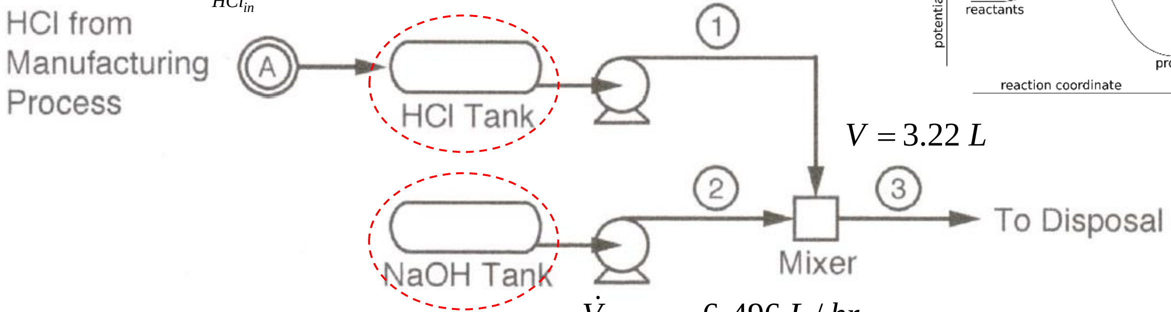
Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 10. Heat Transfer)

$c_{HCl_{in}} = 0.014\ gmol/L$

$T_{HCl_{in}} = 60\ ^{\circ}C$

$\dot{V}_{HCl_{in}} = 11,600\ L/hr$



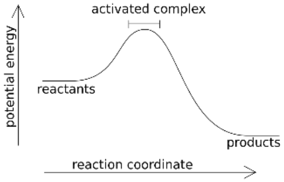
$V = 3.22\ L$

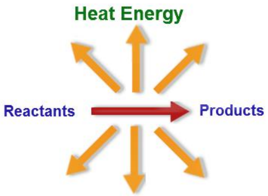
$\dot{V}_{out} = 18,096\ L/hr$

$\dot{V}_{NaOH_{in}} = 6,496\ L/hr$

$c_{NaOH_{in}} = 0.0254\ gmol/L$

$T_{NaOH_{in}} = 32\ ^{\circ}C$





Allowed HCl concentration at final state by law (pH = 6.5)

$c_{HCl_{out}} = 10^{-6.5} = 3.16 \times 10^{-7}\ M$

$c_{NaOH_{out}} = c_{HCl_{out}} = 3.16 \times 10^{-7}\ M$

$$T_f = \frac{\dot{V}_{HCl_i} T_{HCl_i} + \dot{V}_{NaOH_i} T_{NaOH_i}}{\dot{V}_{HCl_i} + \dot{V}_{NaOH_i}} = \frac{(11600\ L/hr)(60^{\circ}C) + (6496\ L/hr)(32^{\circ}C)}{11600\ L/hr + 6496\ L/hr} = 49.9^{\circ}C$$

Allowed temperature of disposal At final state by law ($T \leq 27$°C)

Strategies for solving problems

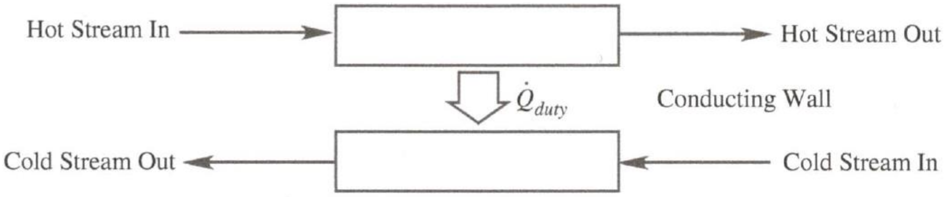
5. Re-evaluate the plane to check desirability (Chapter 10. Heat Transfer)

- **Heat exchanger**

$$Sensible\ cooling: \left[\dot{m}\bar{C}_P\left(T_{out}-T_{in}\right)\right]_{hot} = -\dot{Q}_{duty}$$

$$Phase\ change: \left[\dot{m}\Delta\hat{H}_{phase\ change}\right]_{hot} = -\dot{Q}_{duty}$$

$$Chemical\ reaction: \left[r_{consumption,A}\Delta\tilde{H}_{reaction,A}\right]_{hot} = -\dot{Q}_{duty}$$



$$Sensible\ heating: \left[\dot{m}\bar{C}_P\left(T_{out}-T_{in}\right)\right]_{cold} = \dot{Q}_{duty}$$

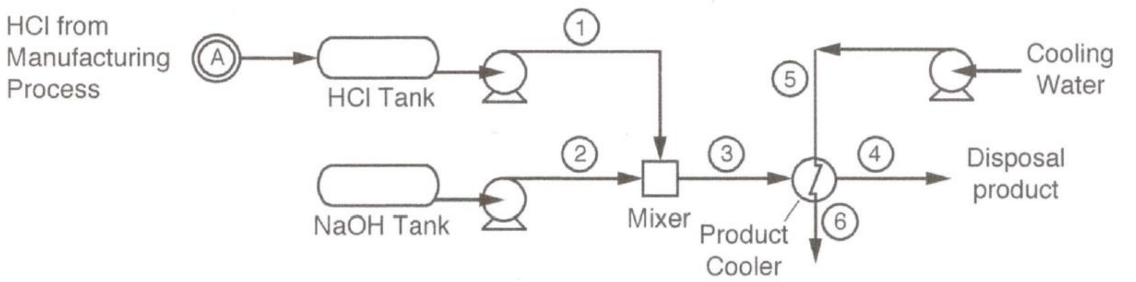
$$Phase\ change: \left[\dot{m}\Delta\hat{H}_{phase\ change}\right]_{cold} = \dot{Q}_{duty}$$

$$Chemical\ reaction: \left[r_{consumption,A}\Delta\tilde{H}_{reaction,A}\right]_{cold} = \dot{Q}_{duty}$$

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 10. Heat Transfer)

- **Process flow diagram (PFD) for the acid-neutralization process with heat exchanger**



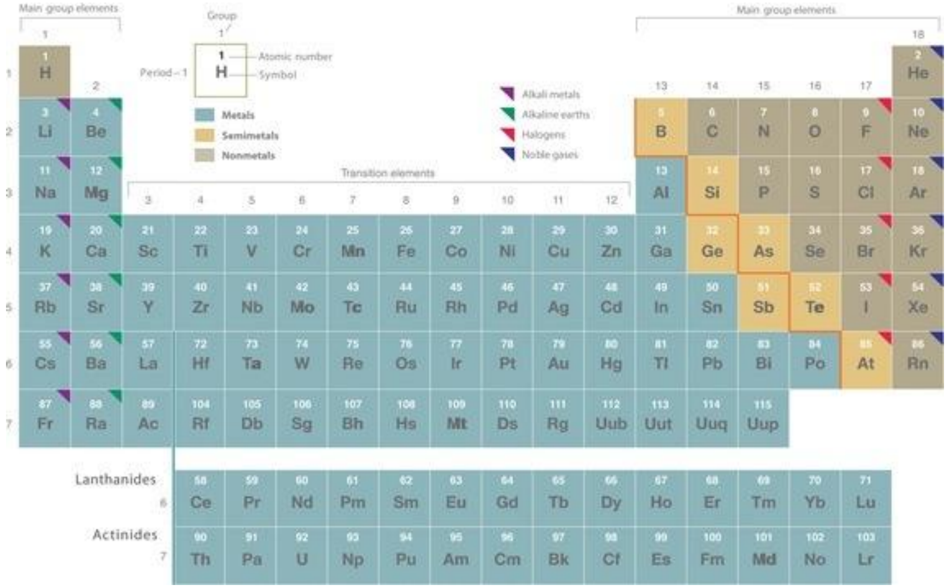
Flows kg/h

Line no. Stream Component	1 Acid feed	2 Base feed	3 Mixer outlet	4 Disp. prod.	5 c.w. inlet	6 c.w. outlet	ABC Chemical Co.	
HCl	6	—	—	—	—	—	Acid neutralization	
NaOH	—	6	—	—	—	—	1x10^8 L/yr	
H_2O	11594	6490	18096	18096	59200	59200	Sheet no. 1	
Total	11600	6496	18096	18096	59200	59200		
Temp. °C	60.0	32.0	49.9	27.0	15.0	22.0	Dwg by	Date
							Checked	1 Sep.2010

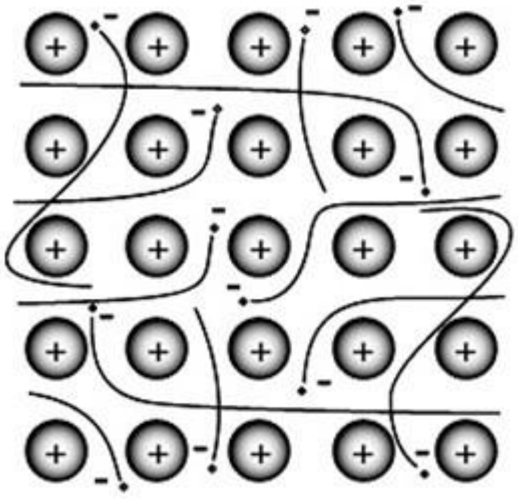
Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 11. Materials)

- **Metal: a material that is typically hard, opaque, shiny and has good electrical and thermal conductivity**



Metallic bonding



Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 11. Materials)

- **Ceramic: an inorganic, nonmetallic solid material comprising metal, nonmetal or metalloid atoms primarily held in ionic and covalent bonds**
- **Examples: alumina (Al_2O_3), silica (SiO_2) and diamond (C)**

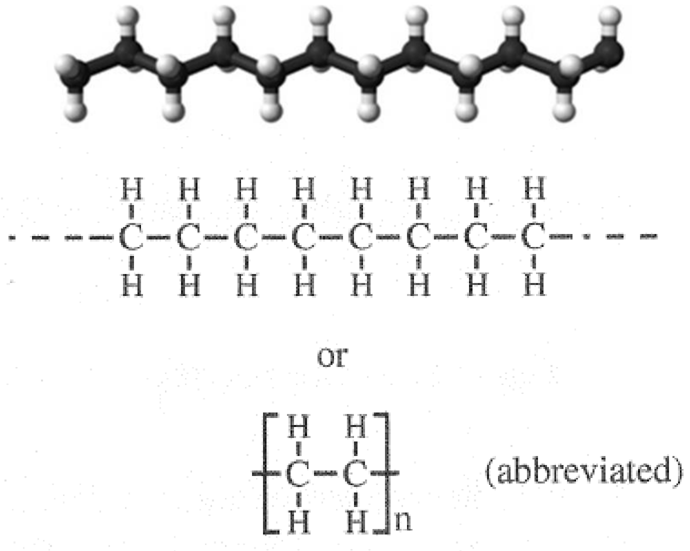
pseudo-ceramic

Strategies for solving problems

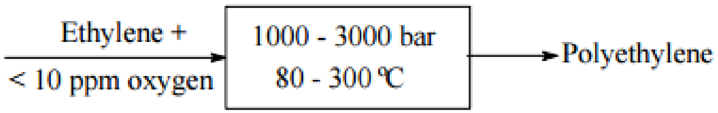
5. Re-evaluate the plane to check desirability (Chapter 11. Materials)

- **Polymer: a large molecule, or macromolecule composed of many repeated subunits**

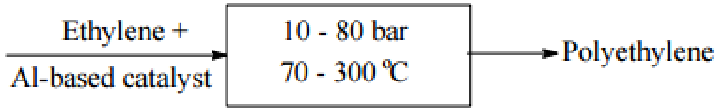
Polyethylene (PE)



High pressure process


Ethylene +
< 10 ppm oxygen
1000 - 3000 bar
80 - 300 ℃
Polyethylene

Low pressure process

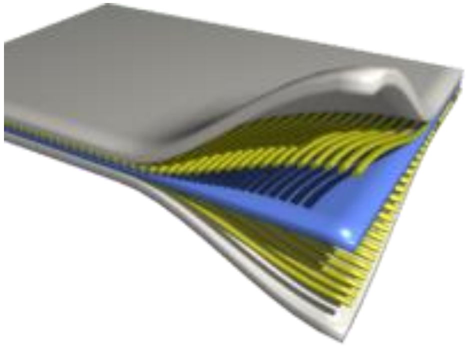

Ethylene +
Al-based catalyst
10 - 80 bar
70 - 300 ℃
Polyethylene

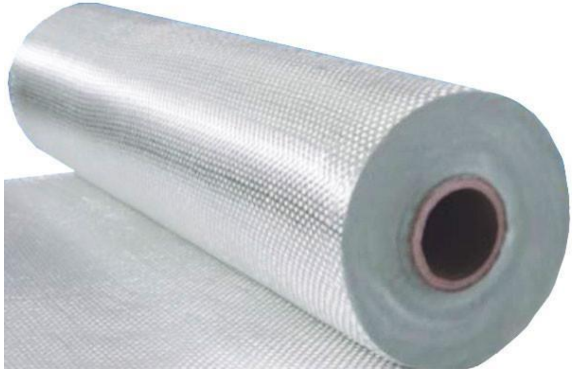
Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 11. Materials)

- **Summary**
  - **Metals** are very strong and easy to work with but are subject to corrosion.
  - **Ceramics** can withstand high temperature and highly reactive environments but are brittle.
  - **Polymers** are very easy to customize, are tough and flexible and are not subject to corrosion but are not strong and cannot withstand high temperature or highly reactive environment.

- **Composite: materials comprised of polymers and either metals or ceramics**





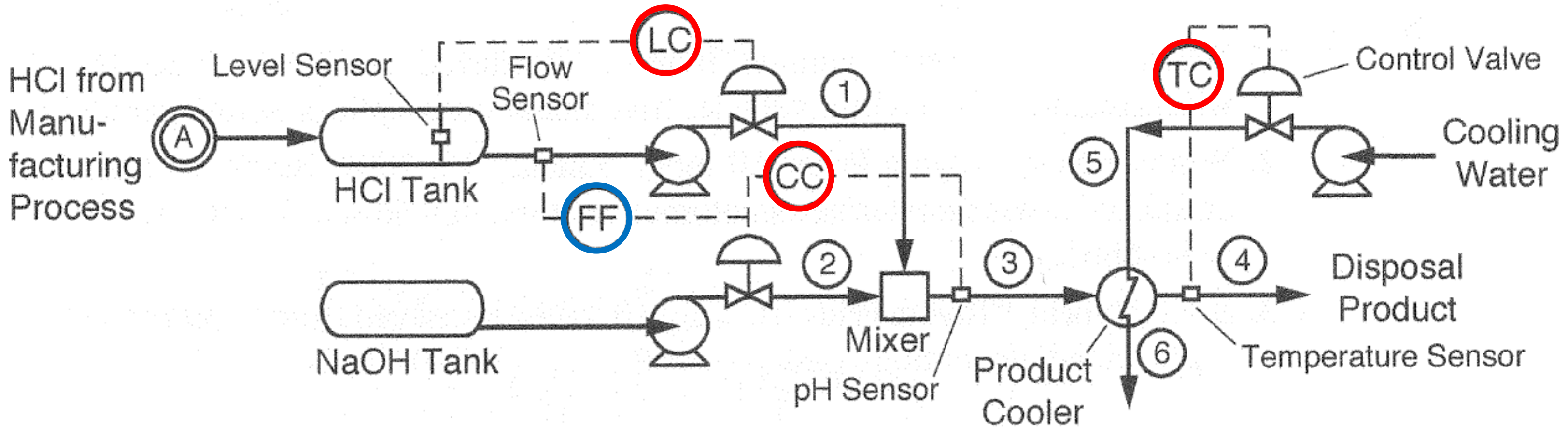
Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 12. Controlling the Process)

- **The acid-neutralization process**

  with feedback control loops including a level controller (LC), temperature controller (TC) and concentration controller (CC)

  with a feedforward controller (FF)



Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 13. Economics)

- **Engineering costs**

Capital costs

- The initial costs
- Purchasing or building
- Reactors, heat exchangers, computers, control valves, piping and etc.

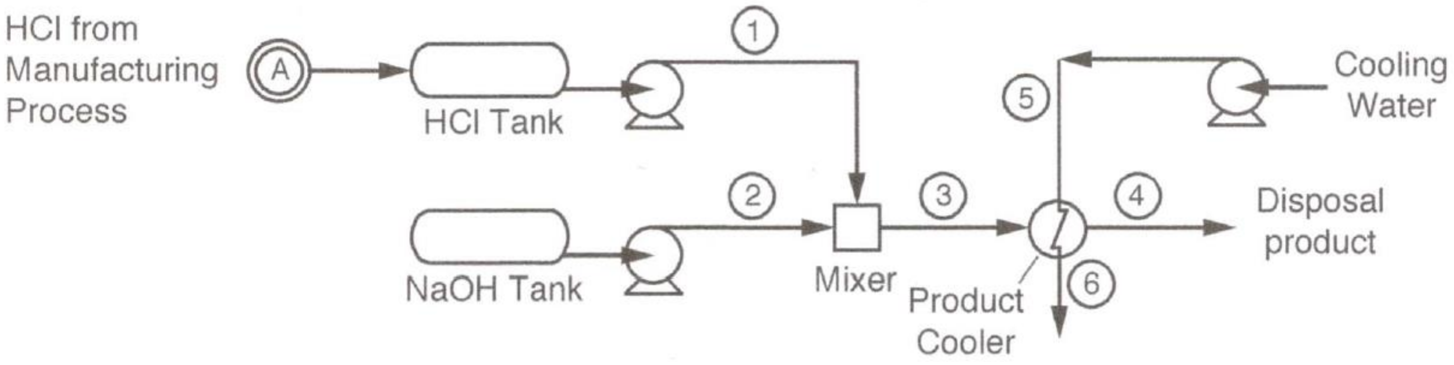
Operating costs

- Day-to-day costs
- Operating equipment and running the process
- Raw materials, pumping, heating, cooling, labor, maintenance

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 13. Economics)

- **Equipment list**
  - HCl tank
  - NaOH tank
  - HCl pump
  - NaOH pump
  - Cooling water pump
  - Heat exchanger



Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 13. Economics)

- **Purchase price of equipments**
  - Volume of HCl and NaOH tanks (capable for 7 days)

$$HCl\ tank: \frac{11{,}600\ L}{hr}\left(\frac{0.26417\ gal}{L}\right)\left(\frac{24\ hr}{day}\right)\left(\frac{7\ days}{week}\right) = 514{,}814\ gal$$

$$NaOH\ tank: \frac{6{,}500\ L}{hr}\left(\frac{0.26417\ gal}{L}\right)\left(\frac{24\ hr}{day}\right)\left(\frac{7\ days}{week}\right) = 288{,}474\ gal$$

  - Estimated purchase prices of HCl and NaOH tanks

$$HCl\ tank: Cost(\$) = \left(\frac{1469}{814}\right)\left[47.0(514{,}814\ gal)^{0.6}\right] = \$258{,}600$$

$$NaOH\ tank: Cost(\$) = \left(\frac{1469}{814}\right)\left[47.0(288{,}474\ gal)^{0.6}\right] = \$181{,}600$$

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 13. Economics)

- **Purchase price of equipments**
  - Estimated purchase prices of pumps

$$HCl\ \ pump: Cost(\$) = \left(\frac{1469}{814}\right)\left[421(51.1\,gal/\min)^{0.46}\right] = \$4,600$$

$$NaOH\ \ pump: Cost(\$) = \left(\frac{1469}{814}\right)\left[421(28.6\,gal/\min)^{0.46}\right] = \$3,600$$

$$Cooling\ \ water\ \ pump: Cost(\$) = \left(\frac{1469}{814}\right)\left[421(191.3\,gal/\min)^{0.46}\right] = \$8,500$$

  - Estimated purchase prices of heat exchanger

$$Heat\ exchanger: Cost(\$) = \left(\frac{1469}{814}\right)\left[398(818\ \ ft^2)^{0.46}\right] = \$56,200$$

Total purchase price of the equipments: $513,100

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 13. Economics)

- **Capital investment**

$$Purchase\ \ price\left(as\ \ just\ calculated\right):\$513{,}100$$

$$Delivered\ \ purchased\ cost:\left(110\%\right)\left(\$513{,}100\right):\$564,400$$

$$Capital\ \ Investment:\left(6.0\right)\left(\$564,400\right)=\$3,386,000$$

- **Gross annual profit**

$$\begin{aligned} Gross\ annual\ \ profit &= Sales - Operating\ costs - Depreciation \\ &= \$6,090,000 - \$4,777,000 - \$339,000 \\ &= \$974,000 \end{aligned}$$

- **Net Annual Profit After Taxes (NAPAT)**

$$\begin{aligned} NAPAT &= \left(1-\phi\right)Gross\ annual\ \ profit, \qquad \phi:\ fractional\ tax\ rate \\ &= \left(1-0.33\right)\left(\$974,000\right) \\ &= \$653,000 \end{aligned}$$

Strategies for solving problems

5. Re-evaluate the plane to check desirability (Chapter 13. Economics)

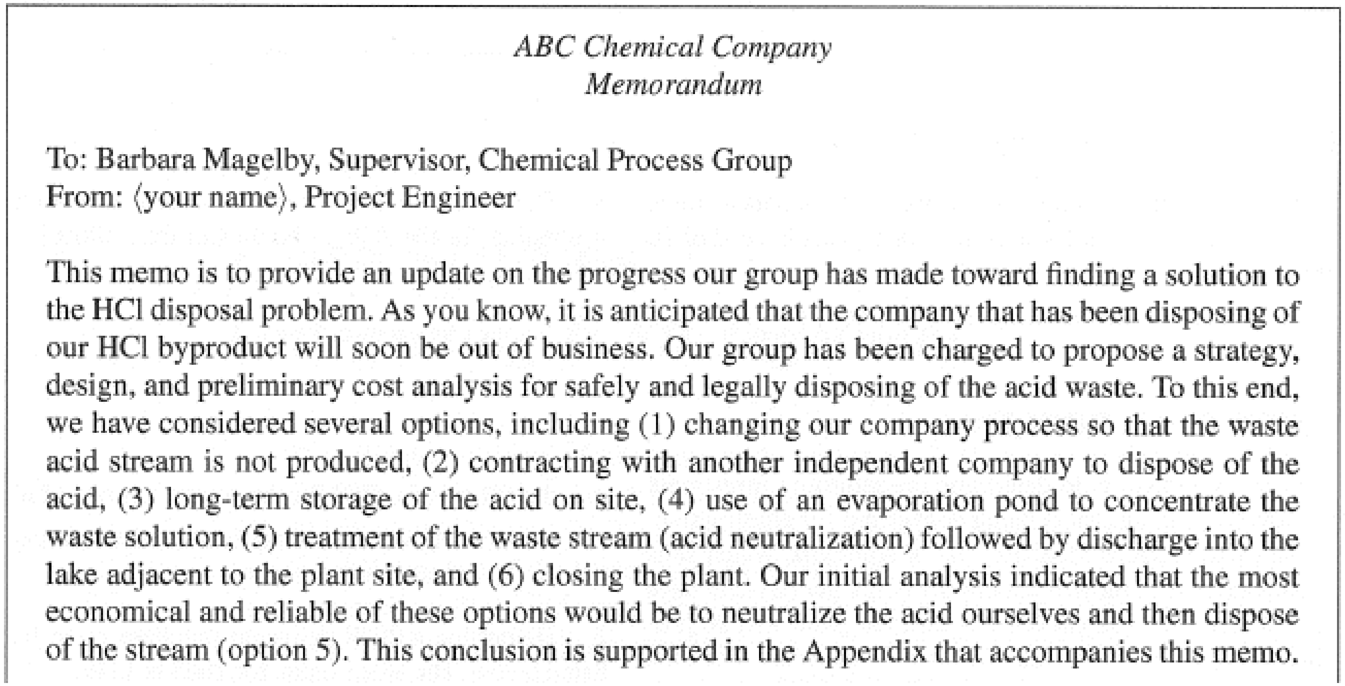
- **Return On Investment (ROI)**

$$
\begin{aligned}
ROI &= \frac{NAPAT}{Capital\ Investment} \\
&= \frac{\$653,000}{\$3,386,000} \\
&= 19.3\%
\end{aligned}
$$

ROI value should be approximately 15% or greater.

Strategies for solving problems

5. Re-evaluate the plane to check desirability



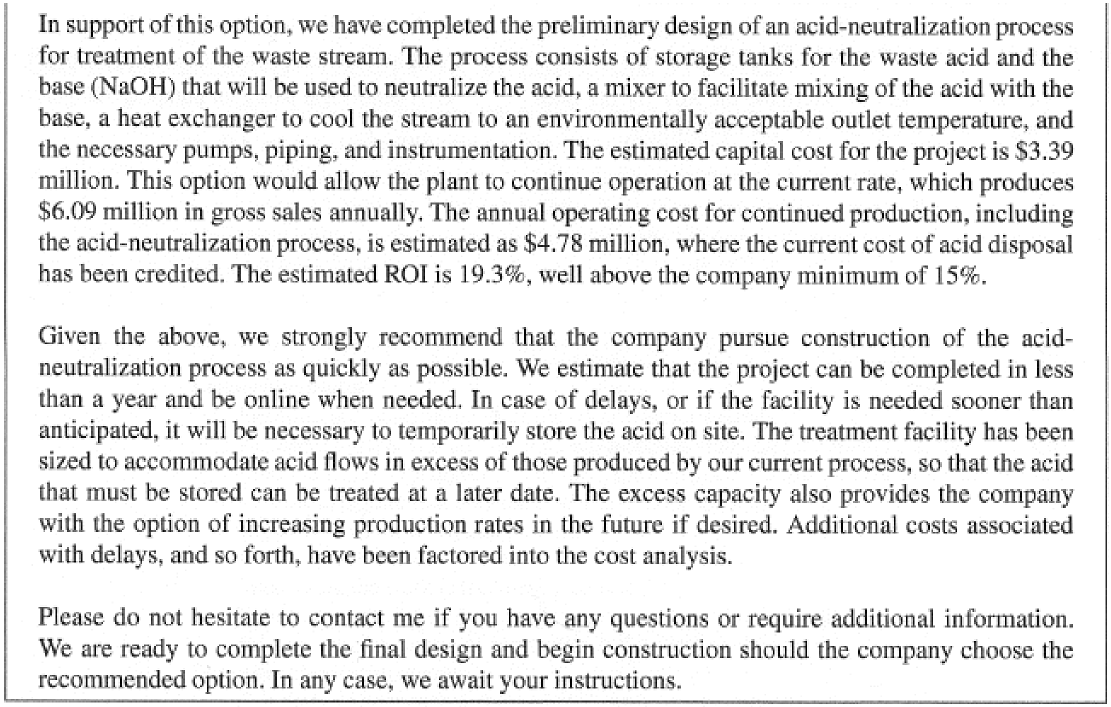
ABC Chemical Company
Memorandum

To: Barbara Magelby, Supervisor, Chemical Process Group
From: ⟨your name⟩, Project Engineer

This memo is to provide an update on the progress our group has made toward finding a solution to the HCl disposal problem. As you know, it is anticipated that the company that has been disposing of our HCl byproduct will soon be out of business. Our group has been charged to propose a strategy, design, and preliminary cost analysis for safely and legally disposing of the acid waste. To this end, we have considered several options, including (1) changing our company process so that the waste acid stream is not produced, (2) contracting with another independent company to dispose of the acid, (3) long-term storage of the acid on site, (4) use of an evaporation pond to concentrate the waste solution, (5) treatment of the waste stream (acid neutralization) followed by discharge into the lake adjacent to the plant site, and (6) closing the plant. Our initial analysis indicated that the most economical and reliable of these options would be to neutralize the acid ourselves and then dispose of the stream (option 5). This conclusion is supported in the Appendix that accompanies this memo.

Strategies for solving problems

5. Re-evaluate the plane to check desirability



In support of this option, we have completed the preliminary design of an acid-neutralization process for treatment of the waste stream. The process consists of storage tanks for the waste acid and the base (NaOH) that will be used to neutralize the acid, a mixer to facilitate mixing of the acid with the base, a heat exchanger to cool the stream to an environmentally acceptable outlet temperature, and the necessary pumps, piping, and instrumentation. The estimated capital cost for the project is $3.39 million. This option would allow the plant to continue operation at the current rate, which produces $6.09 million in gross sales annually. The annual operating cost for continued production, including the acid-neutralization process, is estimated as $4.78 million, where the current cost of acid disposal has been credited. The estimated ROI is 19.3%, well above the company minimum of 15%.

Given the above, we strongly recommend that the company pursue construction of the acid-neutralization process as quickly as possible. We estimate that the project can be completed in less than a year and be online when needed. In case of delays, or if the facility is needed sooner than anticipated, it will be necessary to temporarily store the acid on site. The treatment facility has been sized to accommodate acid flows in excess of those produced by our current process, so that the acid that must be stored can be treated at a later date. The excess capacity also provides the company with the option of increasing production rates in the future if desired. Additional costs associated with delays, and so forth, have been factored into the cost analysis.

Please do not hesitate to contact me if you have any questions or require additional information. We are ready to complete the final design and begin construction should the company choose the recommended option. In any case, we await your instructions.

6. Implement the plan

7. Check the results

Strategies for solving problems

Introduction to
Chemical Engineering

1. Define the problem.
2. List possible solutions.
3. Evaluate and rank the possible solutions.
4. Develop a detailed plan for the most attractive solution(s).
5. Re-evaluate the plan to check desirability.
6. Implement the plan.
7. Check the results.

Chemical Engineering
Fundamentals and Design

1. Necessity of project
2. Motivation and purpose of project
3. Conventional research and technology
4. Problem solving plan and process
5. Concept and detail design
    - 5.1. Goal setting method of design
    - 5.2. Limited factors
    - 5.3. Synthesis
    - 5.4. Analysis
    - 5.5. Evaluation
6. Expected effect
7. Improvement direction

The use of teams in solving problems

Ingredients for a successful team

1. A clear mission or set of goals
2. A plan for attacking problems
3. Clearly defined roles
4. Clear communication
5. Well-defined decision procedures
6. Balanced participation
7. Established ground rules
8. Awareness of group processes

+ more ingredients for a successful team

1. Atmosphere that encourages contribution

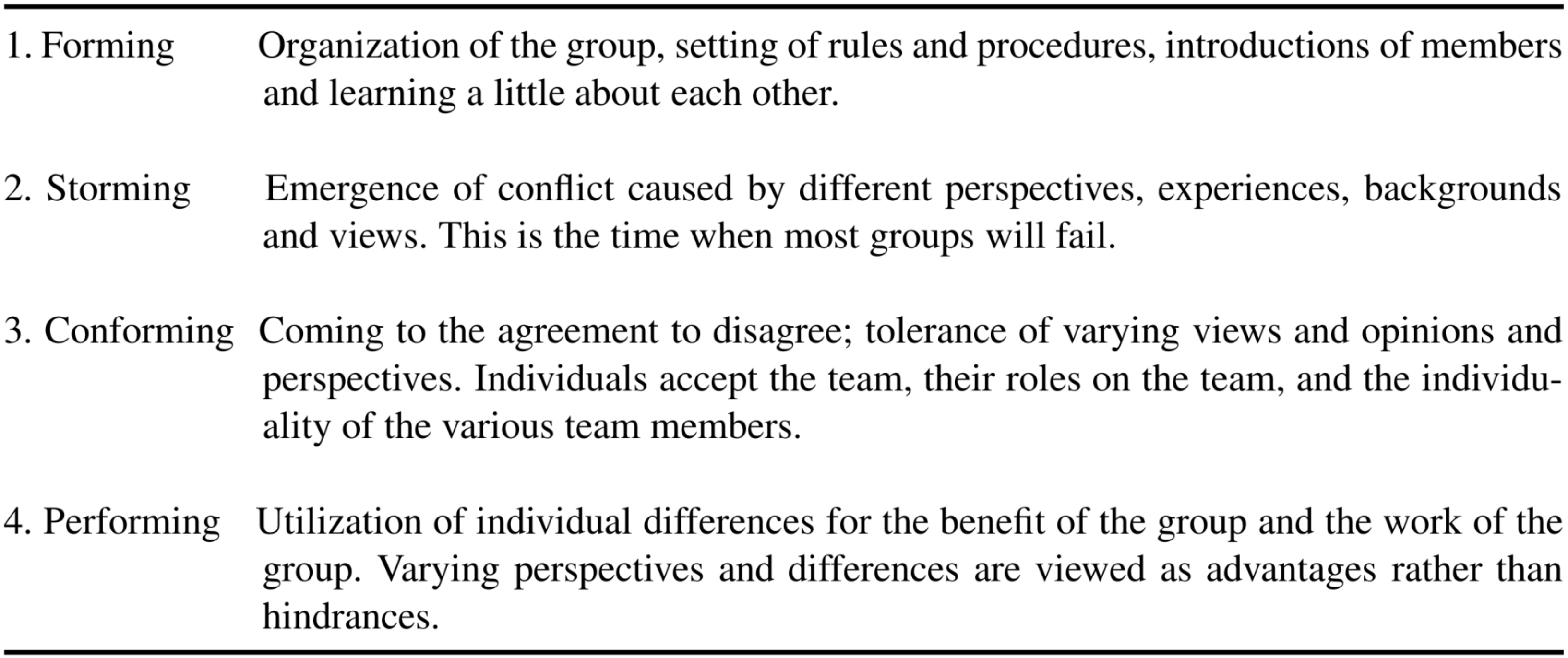
   : positive reinforcement, friendship, trust, diplomacy, sensitivity to other’s needs

2. Individual commitment
3. Individual dependability (follow-through)
4. Individual integrity

The use of teams in solving problems

Learning to work together

Stages of team development



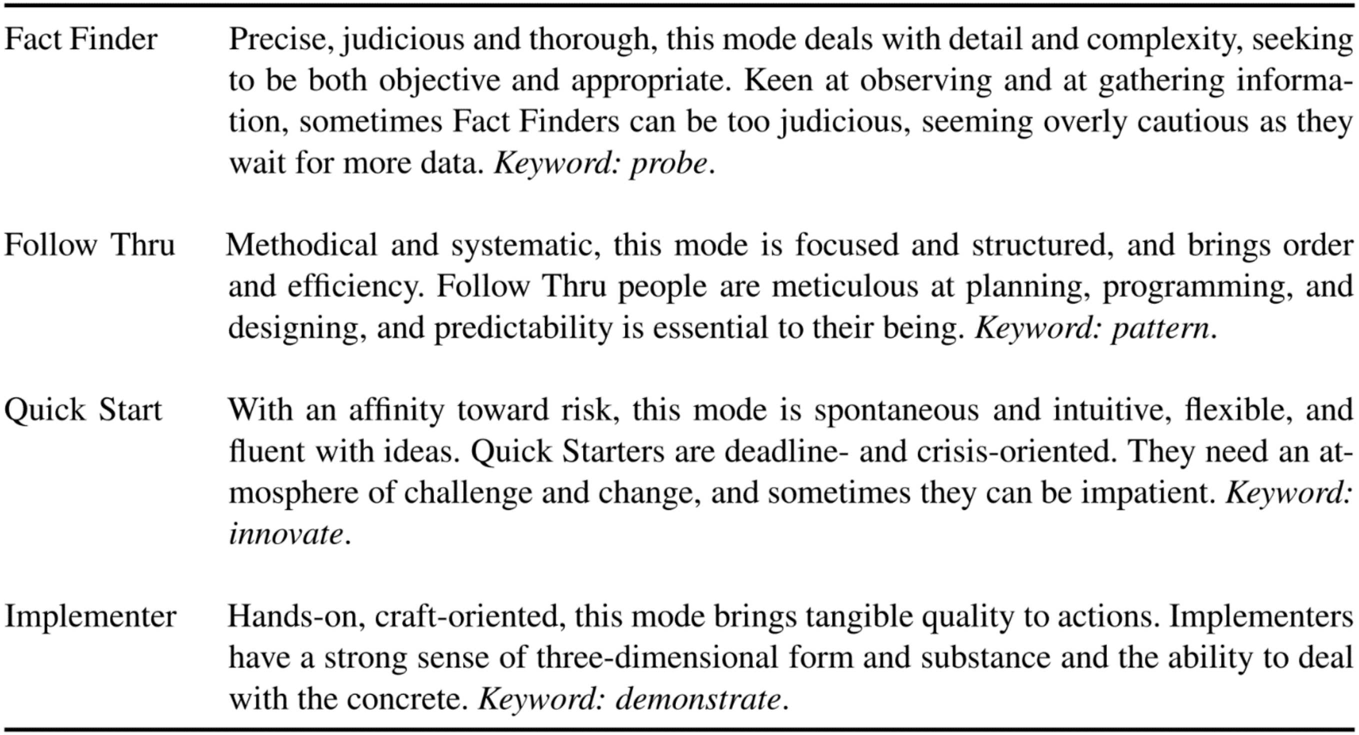
1. Forming	Organization of the group, setting of rules and procedures, introductions of members and learning a little about each other.
2. Storming	Emergence of conflict caused by different perspectives, experiences, backgrounds and views. This is the time when most groups will fail.
3. Conforming	Coming to the agreement to disagree; tolerance of varying views and opinions and perspectives. Individuals accept the team, their roles on the team, and the individuality of the various team members.
4. Performing	Utilization of individual differences for the benefit of the group and the work of the group. Varying perspectives and differences are viewed as advantages rather than hindrances.

adapted from Scholtes, P.R., The Team Handbook for Educators, Madison, WI: Joiner Associates Inc., 1994.

The use of teams in solving problems

Diversity

Characteristic responses to a goal or task



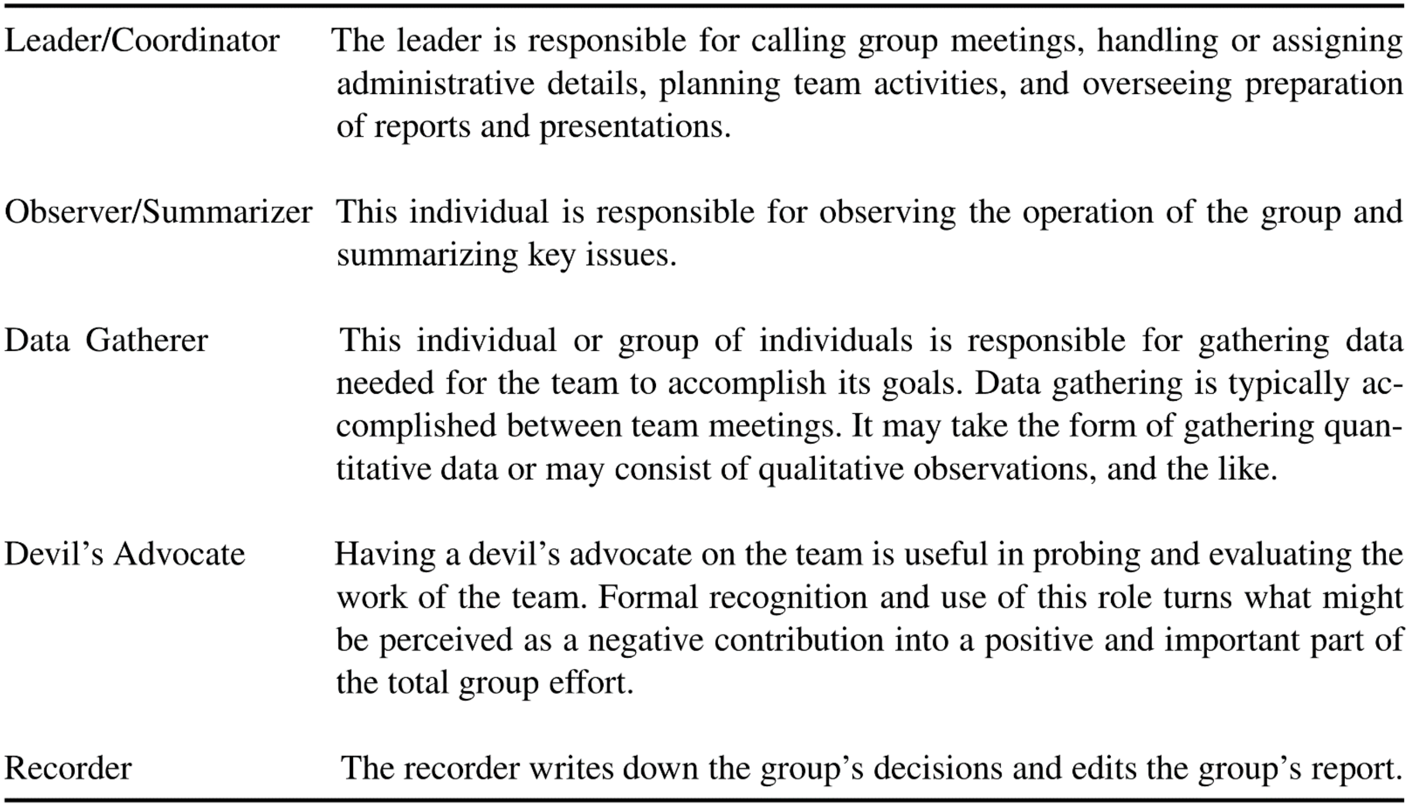
Fact Finder	Precise, judicious and thorough, this mode deals with detail and complexity, seeking to be both objective and appropriate. Keen at observing and at gathering information, sometimes Fact Finders can be too judicious, seeming overly cautious as they wait for more data. *Keyword: probe*.
Follow Thru	Methodical and systematic, this mode is focused and structured, and brings order and efficiency. Follow Thru people are meticulous at planning, programming, and designing, and predictability is essential to their being. *Keyword: pattern*.
Quick Start	With an affinity toward risk, this mode is spontaneous and intuitive, flexible, and fluent with ideas. Quick Starters are deadline- and crisis-oriented. They need an atmosphere of challenge and change, and sometimes they can be impatient. *Keyword: innovate*.
Implementer	Hands-on, craft-oriented, this mode brings tangible quality to actions. Implementers have a strong sense of three-dimensional form and substance and the ability to deal with the concrete. *Keyword: demonstrate*.

adapted from Kolbe, K., The Conative Connection, Menlo Park, CA: Addison-Wesley Publishing Co., 1990.

The use of teams in solving problems

Diversity

Roles within a team structure



Leader/Coordinator	The leader is responsible for calling group meetings, handling or assigning administrative details, planning team activities, and overseeing preparation of reports and presentations.
Observer/Summarizer	This individual is responsible for observing the operation of the group and summarizing key issues.
Data Gatherer	This individual or group of individuals is responsible for gathering data needed for the team to accomplish its goals. Data gathering is typically accomplished between team meetings. It may take the form of gathering quantitative data or may consist of qualitative observations, and the like.
Devil's Advocate	Having a devil's advocate on the team is useful in probing and evaluating the work of the team. Formal recognition and use of this role turns what might be perceived as a negative contribution into a positive and important part of the total group effort.
Recorder	The recorder writes down the group's decisions and edits the group's report.