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APPENDICES

Appendix A Results From Analysis Methods

Table A1 shows the water content of the samples before doing experiment by heat in oven at 120 °C for 10 hrs. After that the samples are weighted to determine remaining weight of the samples compare to initial weight.

Table A2 shows the composition of the samples from both combustion, and extraction and precipitation by XRF analysis. The elements are represented as oxide compounds.

Figure A1-A7 shows results from XRD analysis for each treated samples.

Table A1 Water content of waste solid samples

	Water Content (%wt)
Repeat 1	7.36
Repeat 2	7.91
Repeat 3	7.58
Average	7.62

Table A2 XRF results from treated sample

Combustion	Concentration (%wt)		
	K_2O	SO_3	Other
700°C/20 mins	60.04	39.55	0.41
900°C/20 mins	60.20	39.52	0.28
Extraction and Precipitation	Concentration (%wt)		
	K_2O	SO_3	Other
EtOH 10 ml	66.396	33.518	0.086
EtOH 20 ml	66.906	33.033	0.061
EtOH 30 ml	65.710	34.093	0.197
EtOH 40 ml	67.196	32.475	0.329
EtOH 50 ml	66.990	32.818	0.192
MeOH 10 ml	65.960	34.011	0.299
MeOH 20 ml	66.285	33.574	0.141
MeOH 30 ml	66.788	33.092	0.12
MeOH 40 ml	67.200	32.661	0.139
MeOH 50 ml	67.495	32.296	0.309

*Samples were dissolved by 50 ml water.

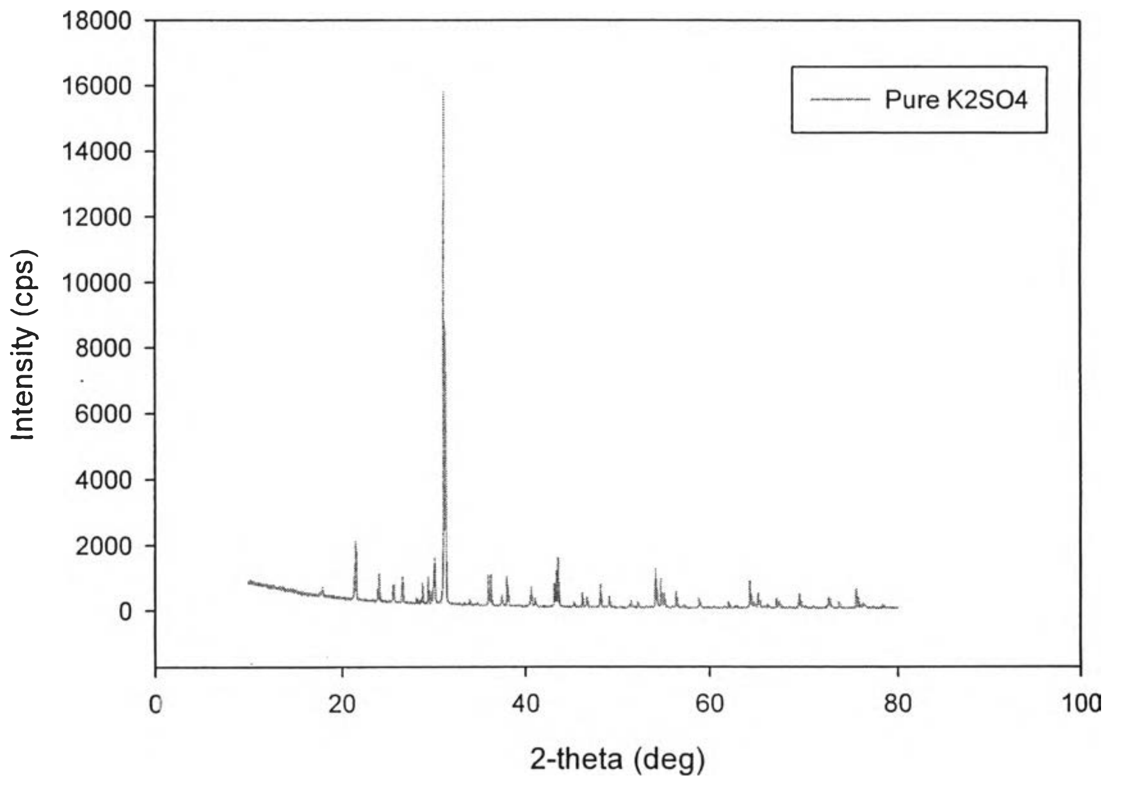

Figure A1 XRD result of pure K_2SO_4.

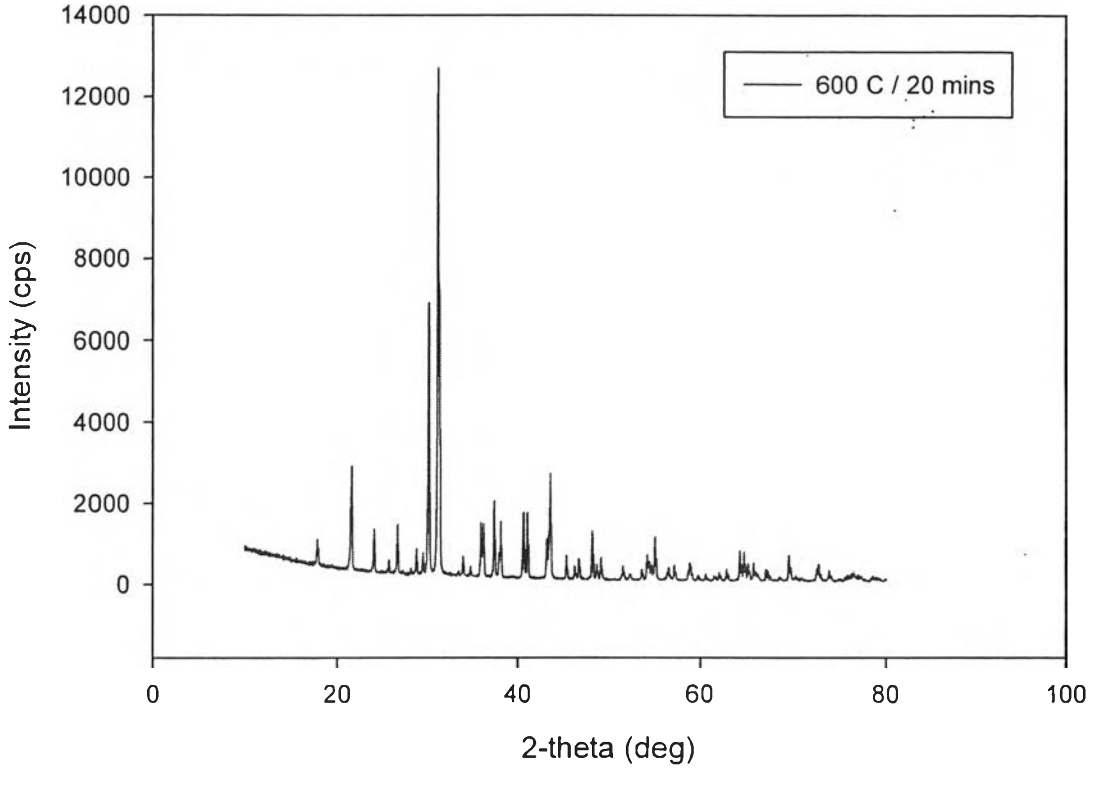

Figure A2 XRD result of treated sample (600 °C / 20 mins).

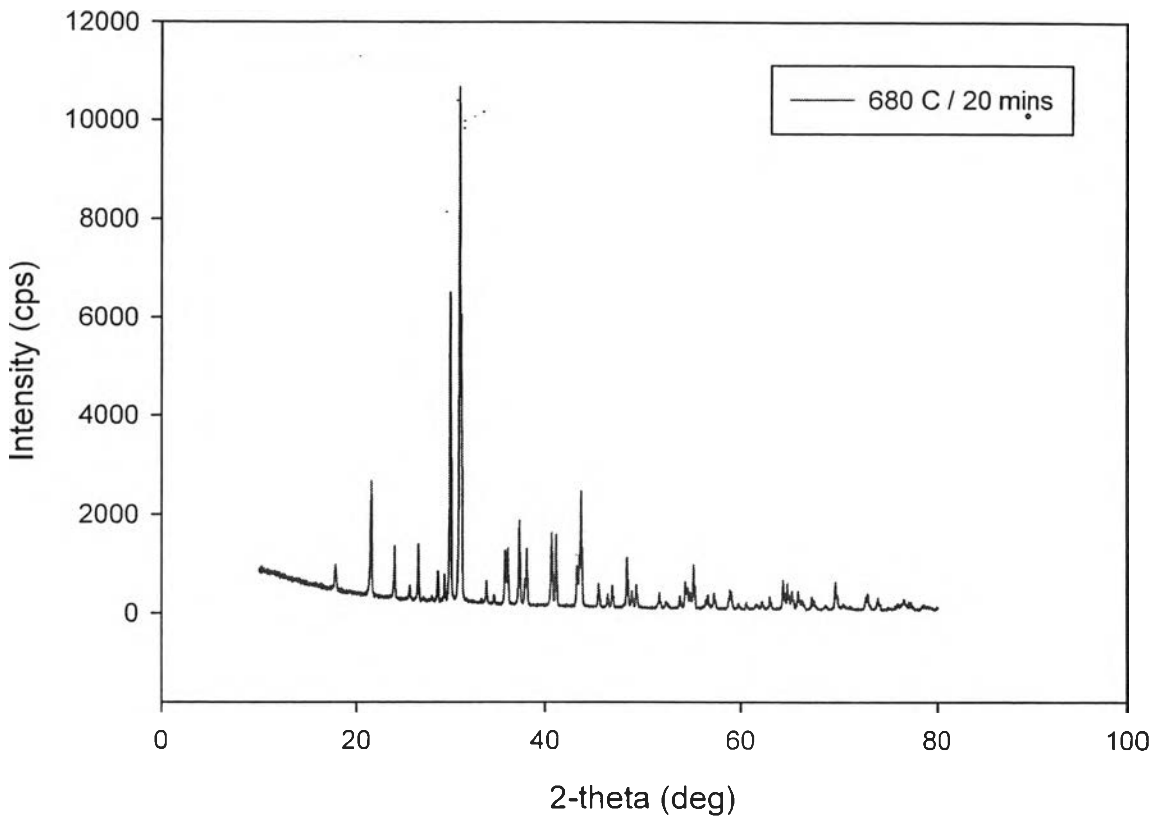

Figure A3 XRD result of treated sample (680 °C / 20 mins).

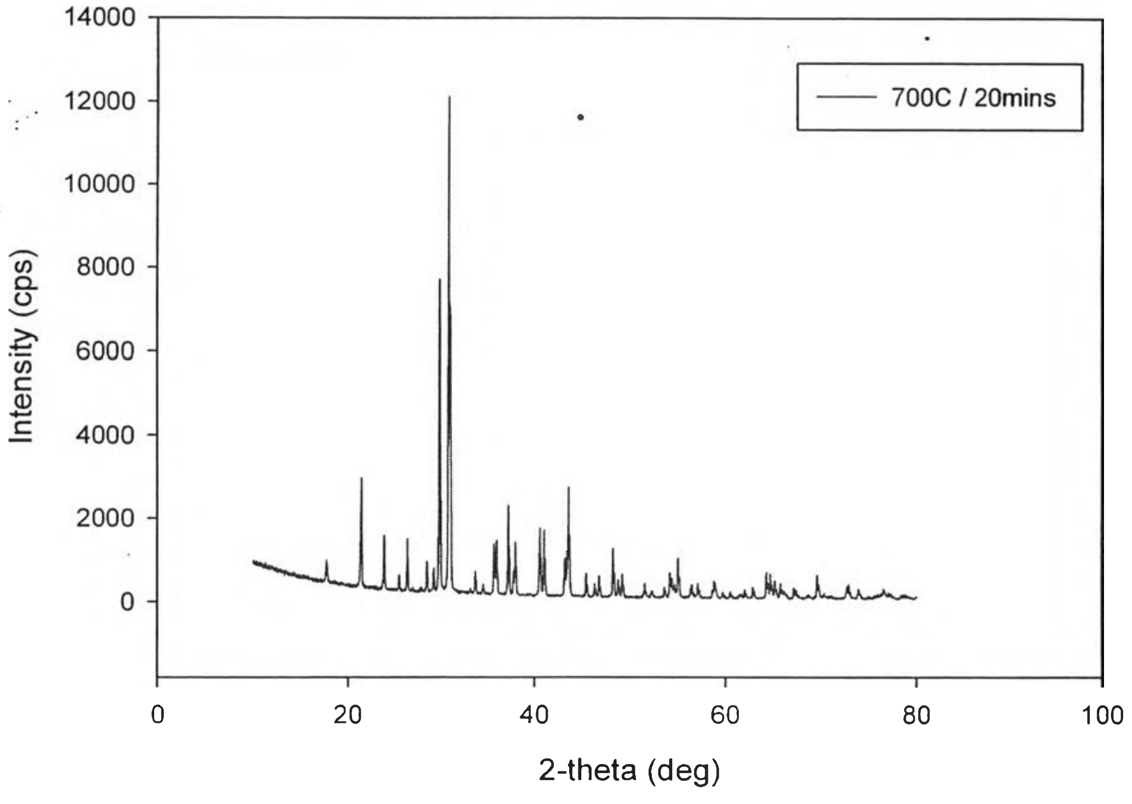

Figure A4 XRD result of treated sample (700 °C / 20 mins).

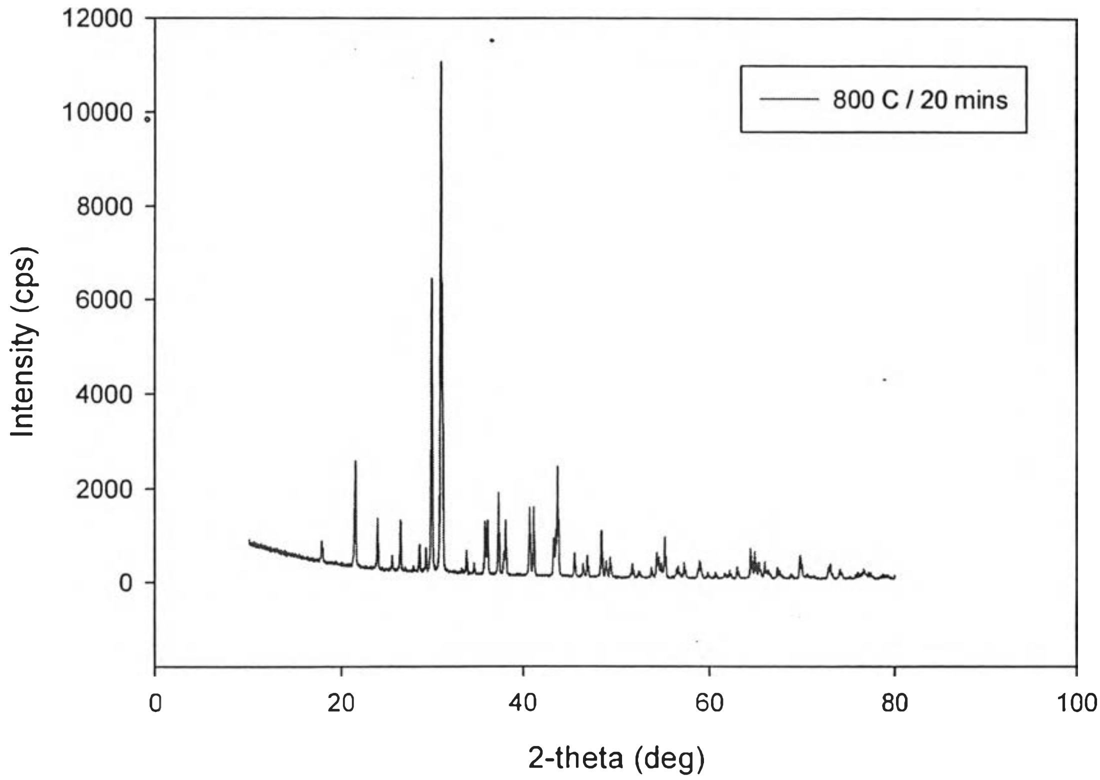

Figure A5 XRD result of treated sample (800 °C / 20 mins).

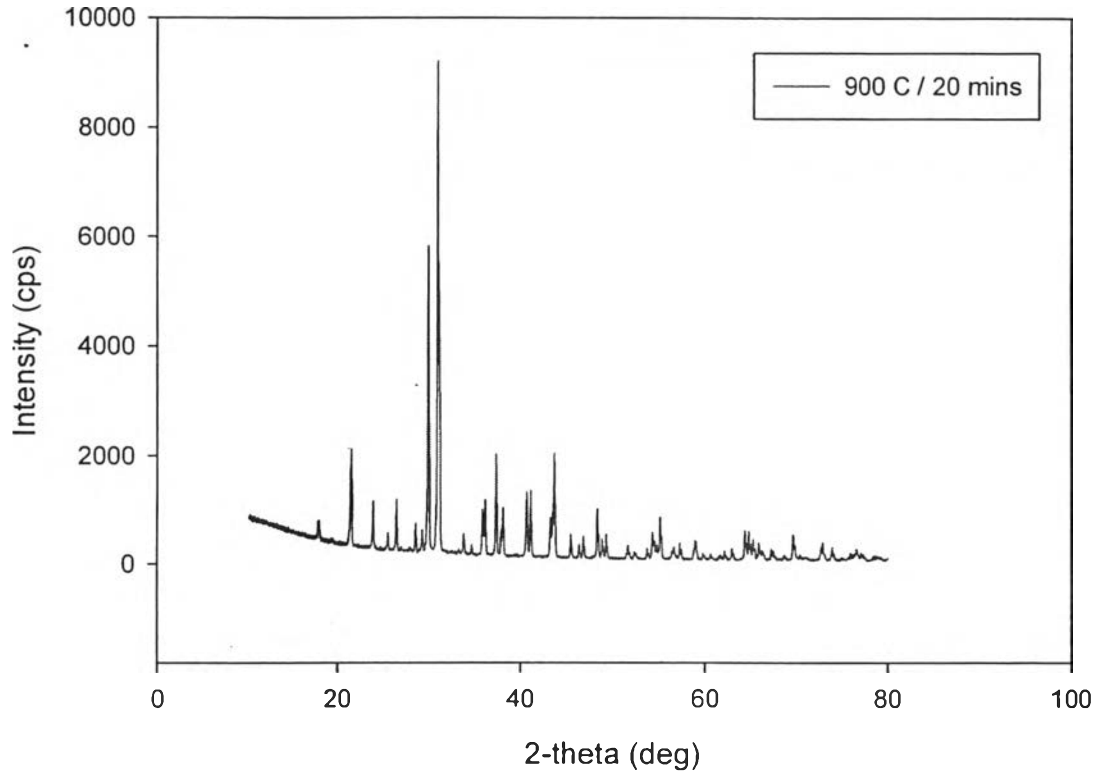

Figure A6 XRD result of treated sample (900 °C / 20 mins).

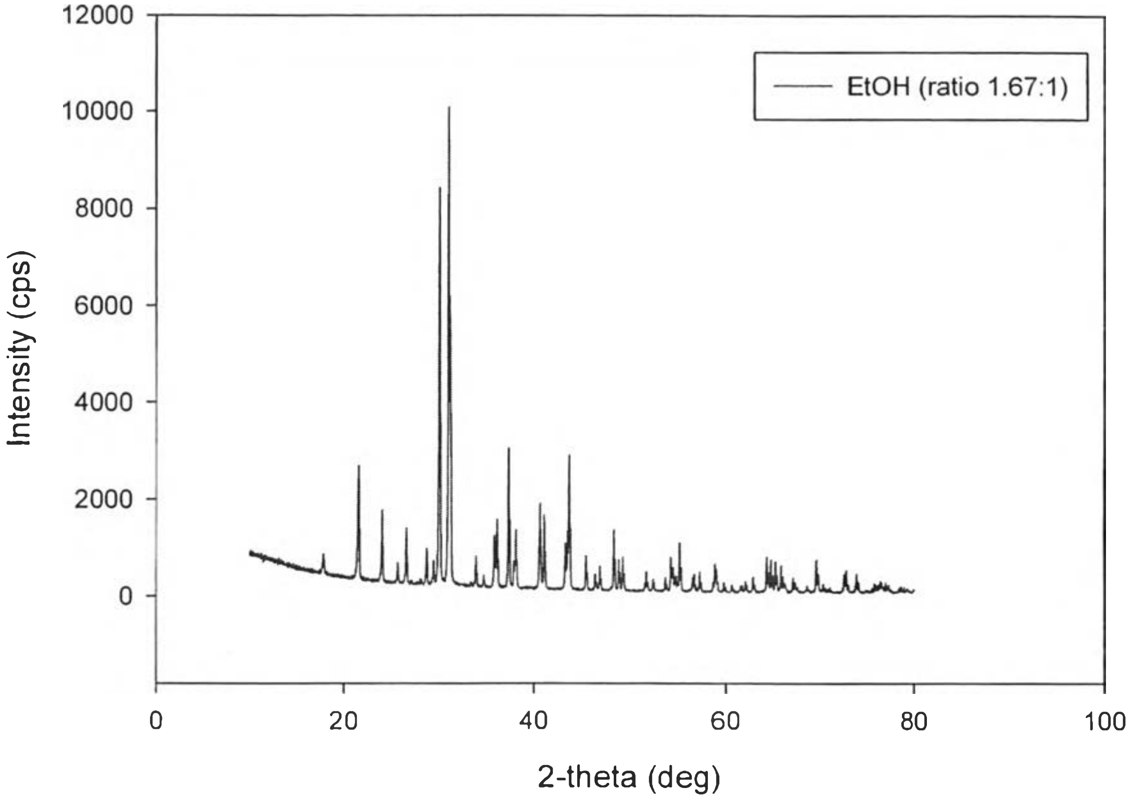

Figure A7 XRD result of treated sample (EtOH, ratio 5:3).

Appendix B Percent Weight Recovery Calculation

Table B1 shows the results collected from combustion, and the calculation for determining percent weight recovery is shown below.

Table B1 Result of treated sample from combustion

Sample (g)	4.43
Temperature (°C)	700
Duration (mins)	20
Crucible (g)	32.35
Total weight (g)	36.47
Treated Sample (g)	4.12

From $$\%wt.\ Recovery = \frac{W_f}{W_i} x 100$$

$W_i = 4.43$ g

$W_f = 4.12$ g

$$\%wt.\ Recovery = \frac{4.12}{4.43} x 100$$

So %wt. Recovery = 93.0 %

Appendix C Precipitated Salt Calculation

Table C1 shows the results collected from extraction and precipitation, and the calculation for determining percent weight of precipitated salt is shown below.

Table C1 Result from extraction and precipitation

Sample (g)	9.38
Water (ml)	50.00
Alcohol (ml)	40.00
Ratio	5 : 4
Precipitated salt	
*Salt from filter (g)	5.79
*Salt from flask (g)	0.54
Precipitated salt (g)	6.33
Evaporation	
Remaining salt (g)	0.60

From $W_{total\ dissolved\ salt} = W_{precipitated\ salt} + W_{remaining\ salt}$

$W_{precipitated\ salt} = 6.33$ g

$W_{remaining\ salt} = 0.60$ g

So $W_{total\ dissolved\ salt} = 6.33 + 0.60 = 6.93$ g

From $$\%Precipitated\ Salt = \frac{W_{precipitated\ salt}}{W_{total\ dissolved\ salt}} x100$$

$$\%Precipitated\ Salt = \frac{6.33}{6.93} x100$$

%Precipitated Salt = 91.34 %

Appendix D Instrument Cost Estimation

Figure D1-D8 shows the cost of purchased equipment which used for cost estimation.

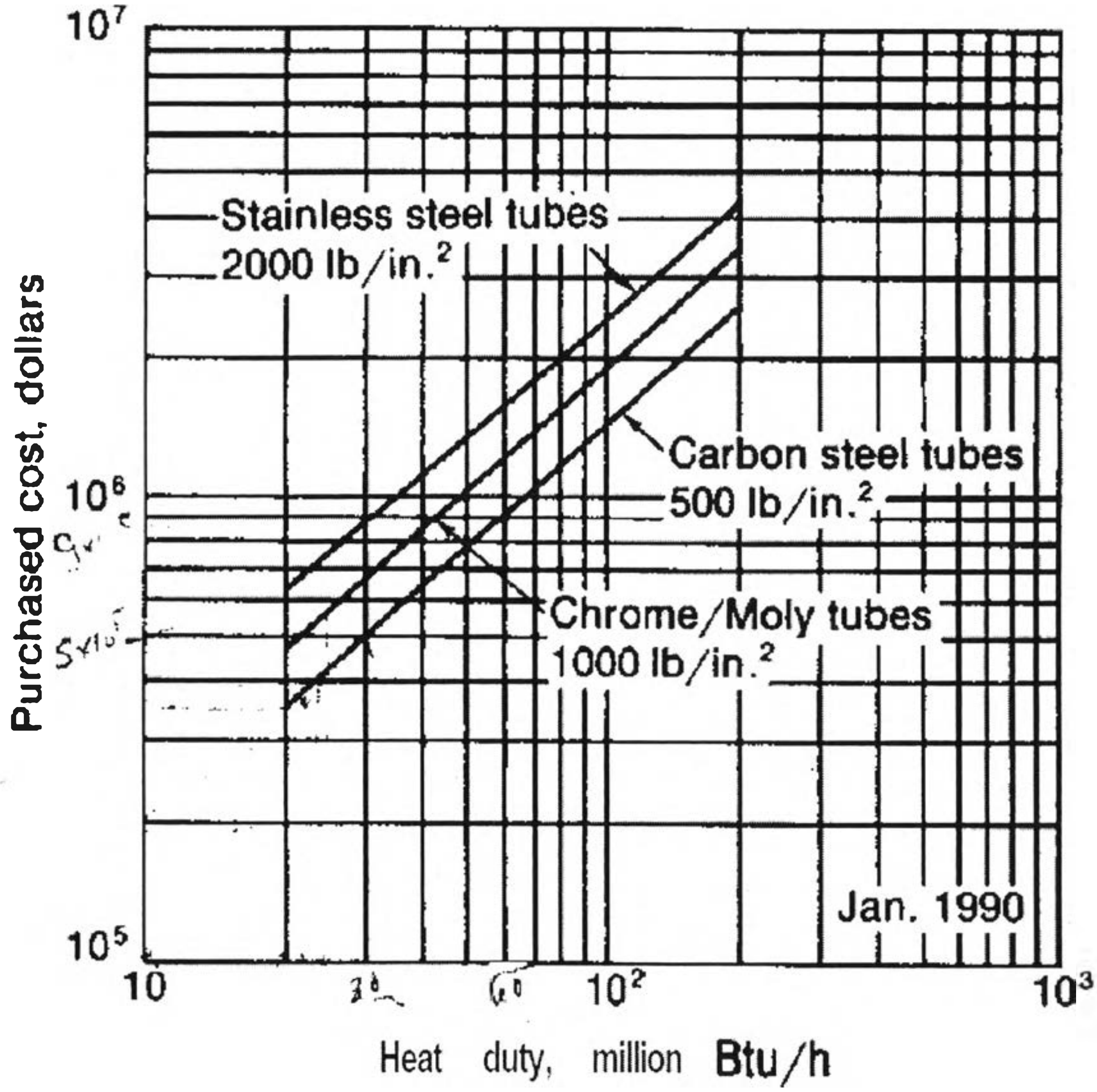

Figure D1 Cost of process furnaces, box type with horizontal radiant tubes.

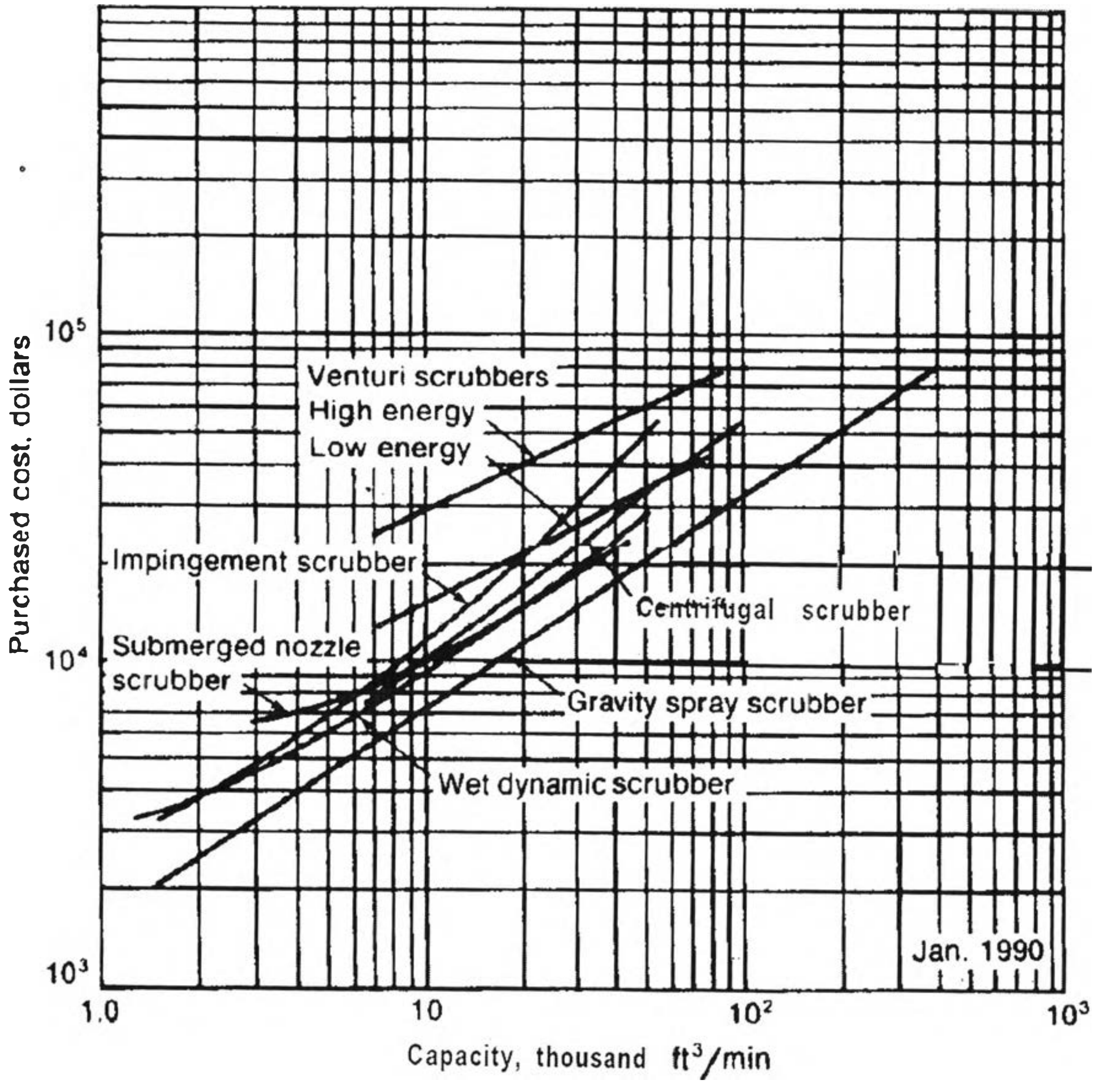

Figure D2 Cost of wet dust collector.

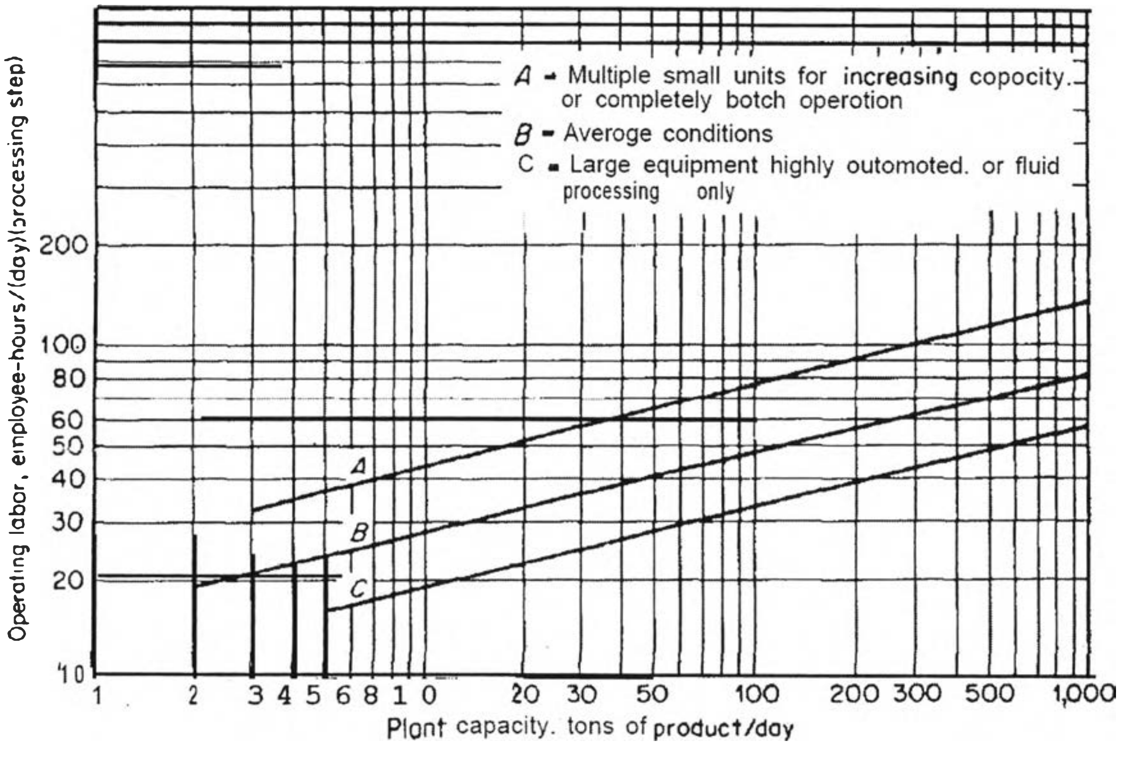

Figure D3 Operating labor requirements for chemical process industries.

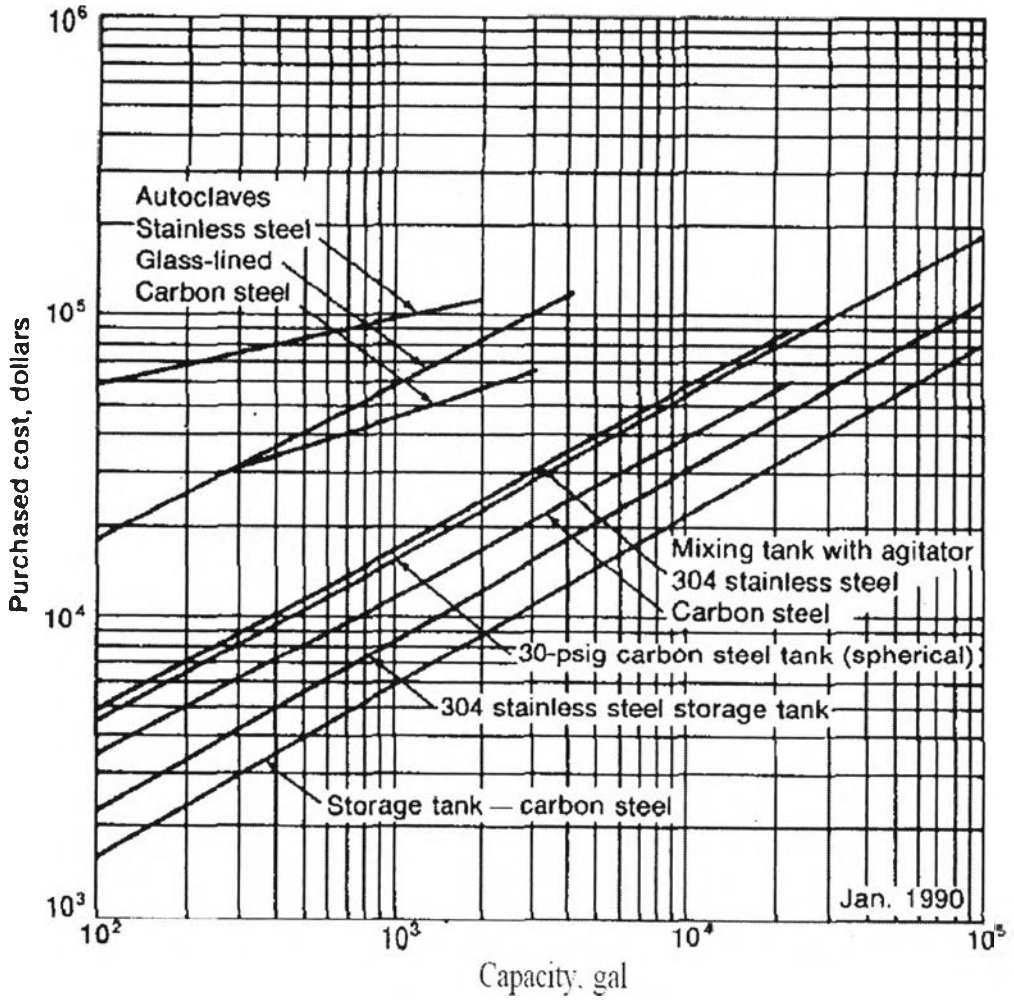

Figure D4 Cost of mixing, storage, and pressure tanks. Price for the mixing tank includes the cost of driving unit.

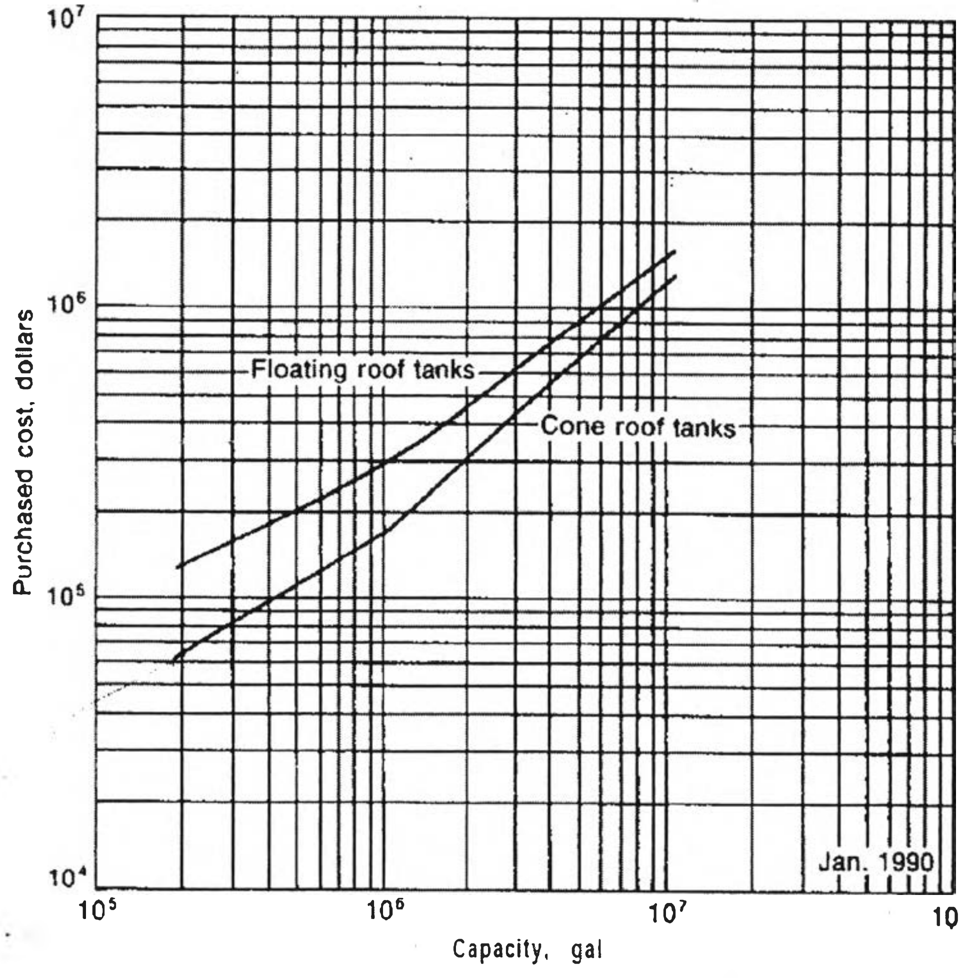

Figure D5 Cost of large-volume carbon-steel storage tank.

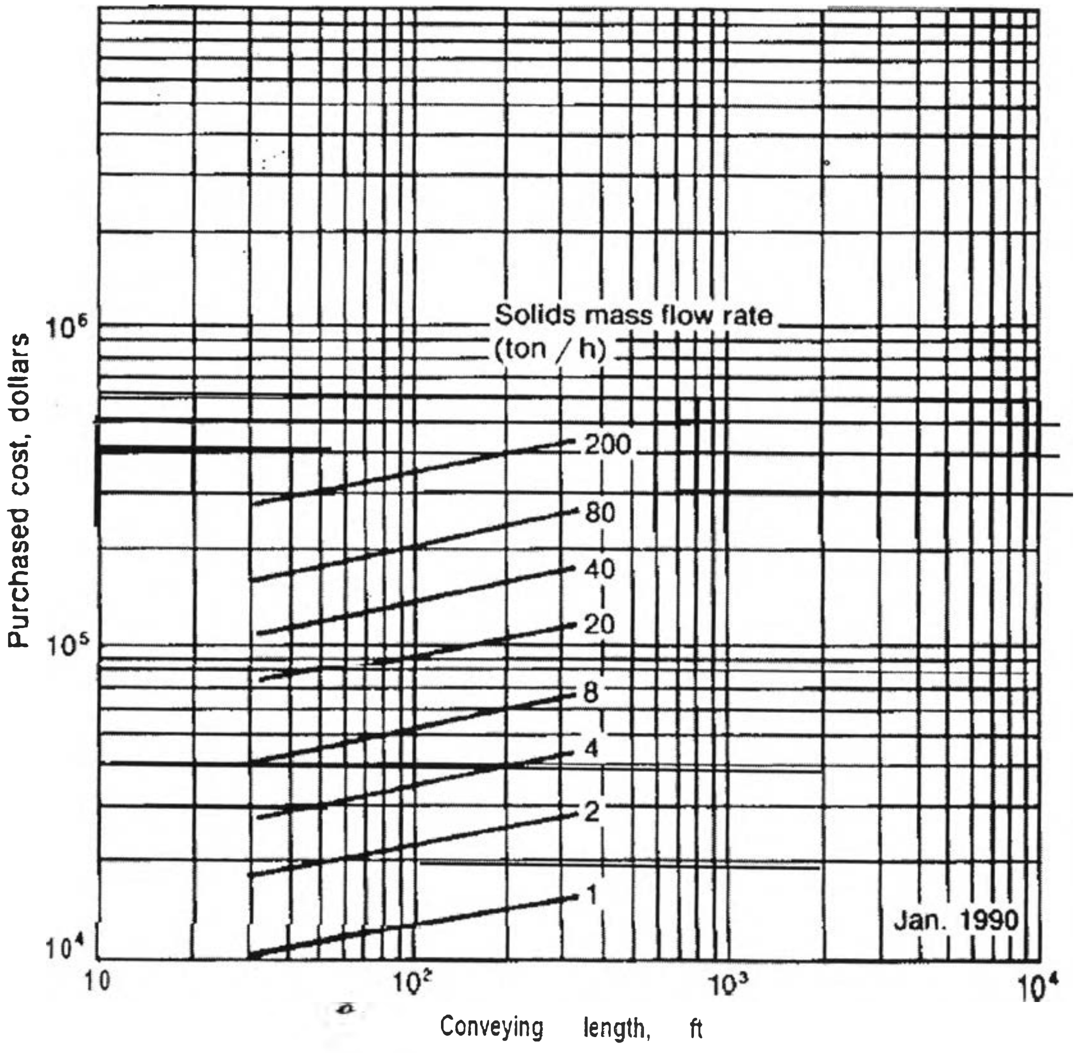

Figure D6 Purchased equipment costs for pneumatic solids-conveying equipment (Drives are included).

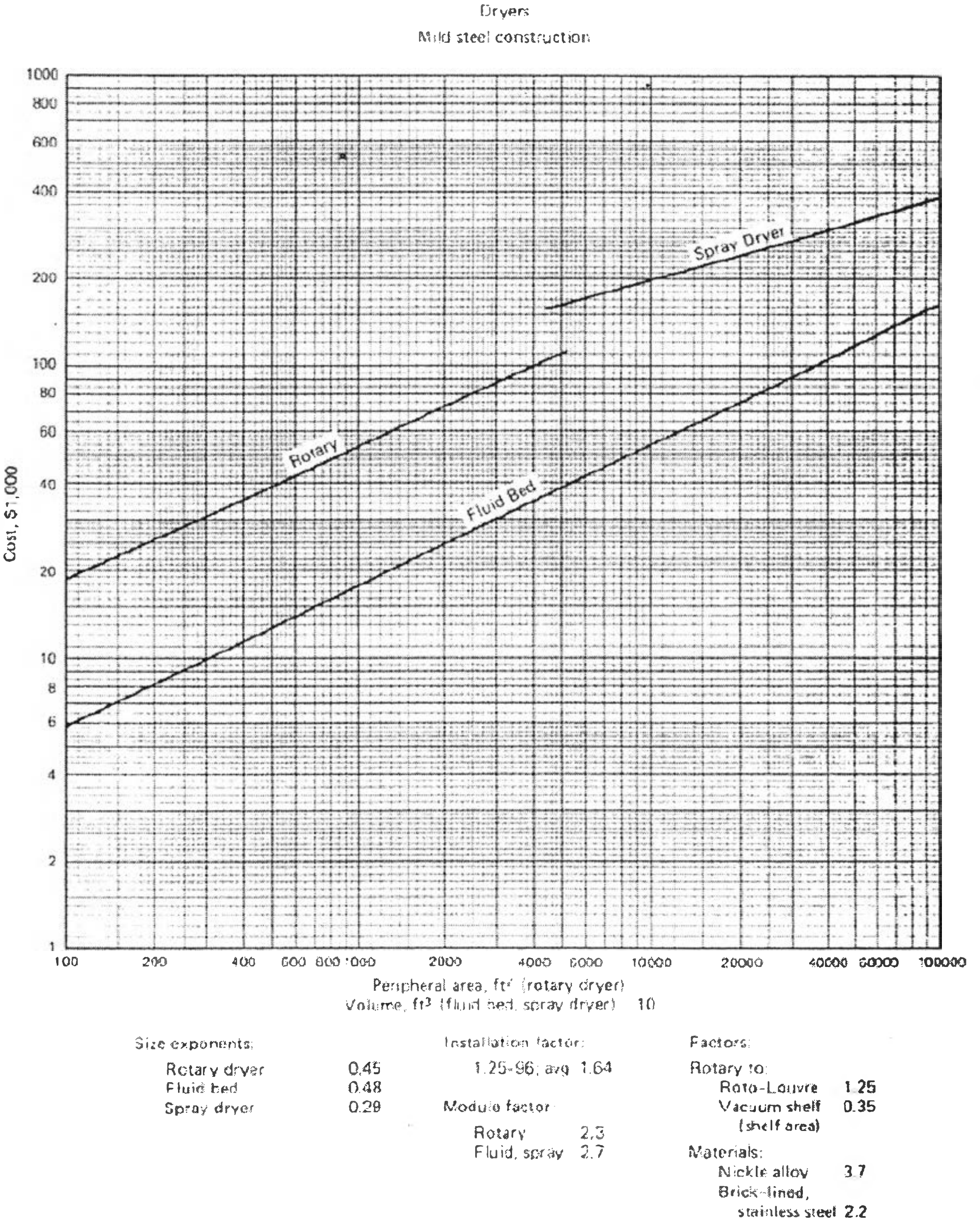

Figure D7 Purchased equipment cost for dryer.

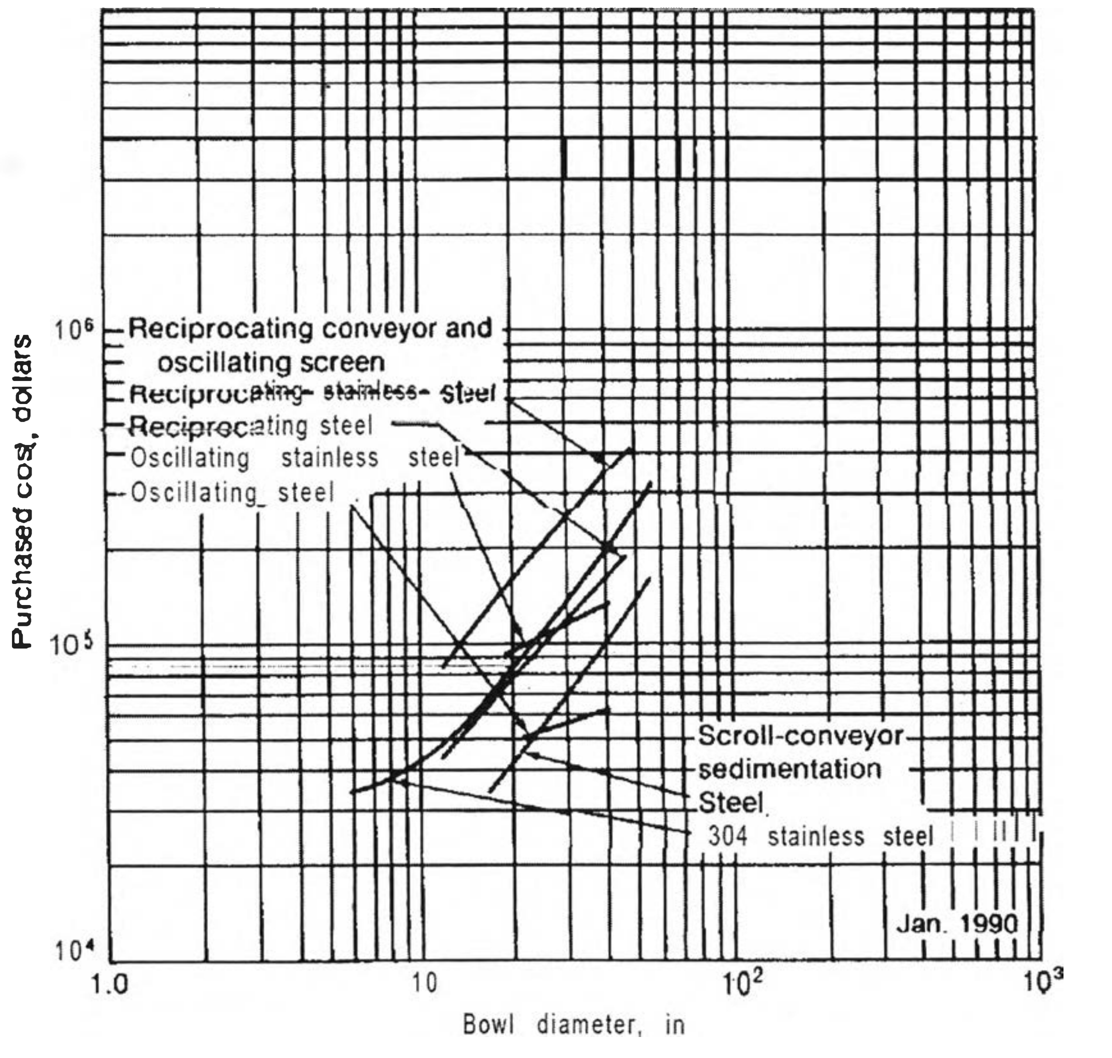

Figure D8 Cost for Centrifugal separator (Scroll-conveyor sediment separator).

Appendix E Industrial Utility Cost

Table E1 shows the cost for each utility, this information is referred from Jan 1990.

Table E2 shows the cost of chemical industry in term of cost per unit.

Table E1 Rates for various industrial utilities

Utility	Condition	Cost ($) (Jan. 1990)
Steam	1. 500 psig	3.25-3.90/1,000 lb
	2. 100 psig	1.50-3.20/1,000 lb
	3. Exhaust	0.80-1.50/1,000 lb
Electricity	1. Purchased	0.035-0.13/kWh
	2. Self-generated	0.025-0.065/kWh
Cooling Water	1. Well	0.10-0.50/1,000 gal
	2. River of salt	0.06-0.20/1,000 gal
	3. Tower	0.06-0.26/1,000 gal
Process Water	1. City	0.35-1.50/1,000 gal
	2. Filtered and softened	0.50-1.50/1,000 gal
	3. Distilled	2.25-4.00/1,000 gal
Compressed Air	1. Process air	0.06-0.20/1,000 ft^3 (atSC)*
	2. Filtered and dried for instruments	0.12-0.36/1,000 ft^3 (atSC)*
Natural Gas	1. Major pipeline companies	2.40-3.15/1,000 ft^3 (atSC)*
	2. New contracts	2.40-3.50/1,000 ft^3 (atSC)*
	3. Regenerated or amended contracts	2.75-3.75/1,000 ft^3 (atSC)*
Manufactured Gas	1. Fuel oil	17.00-24.00/bbl
	2. Coal	30.00-55.00/ton
	3. Refrigeration (ammonia), to 34°F	2.00/ton-day

*Standard conditions are designed as a pressure of 29.92 in Hg and a temperature of 60°F.

Table E2 Costs for selected industrial chemicals

Chemical and Conditions	**Unit**	**Cost ($) (Jan. 1990)**
Acetaldehyde, 99%, tanks	lb	0.47
Acetic acid, tech., tanks	lb	0.29
Acetic anhydride, tanks	lb	0.46
Acetone, tanks	lb	0.29
Acrylonitrile, tanks	lb	0.45
Allyl alcohol, tanks, Bayport, Texas	lb	1.00
Ammonia, anhyd., fertilizer, tanks, Midwest	ton	110.00
Aniline, tanks	lb	0.57
Benzaldehyde, tech., drums	lb	0.73
Benzene, indust., barges	gal	1.50
Benzoic acid, tech., bags	lb	0.55
n-Butyl alcohol, syn., ferment., tanks	lb	0.39
Butyric acid, tanks	lb	0.76
Calcium carbonate, nat., dry-ground, carlots	ton	49.00
Carbon tetrachloride, tech., drums, carlots	lb	0.31
Chlorine, tanks	ton	190.00
Chloroform, tech., tanks, delivered	lb	0.36
Copper chloride (cupric), anhyd., carlots	lb	2.37
Ethyl alcohol, 190 proof, USP tax free, tanks	gal	2.00
Ethyl ether, refined, tanks	lb	0.52

Table E2 Costs for selected industrial chemicals (Cont.)

Chemical and Conditions	**Unit**	**Cost ($) (Jan. 1990)**
Ethylene, contract, delivered	lb	0.24
Ethylene oxide, tanks	lb	0.60
Formaldehyde, 37% by wt., inhibited 7% methanol, tanks, Gulf coast	lb	0.10
Glycerine, syn., 99.7%, tanks, delivered	lb	0.85
Hexane, indust., tanks	gal	0.74
Hydrochloric acid, 20"Be, tanks	ton	55.00
Isobutyl alcohol, tanks, delivered	lb	0.39
Methanol, syn., barges, Gulf coast	gal	0.32
Nitric acid, 36 Be, tanks	ton	175.00
Oxalic acid, bags, carlots	lb	0.60
Pentaerythritol, tech., bags, carlots	lb	0.71
Phenol, syn., tanks	lb	0.41
Propylene glycol, indust., tanks	lb	0.56
Soda ash, dense, 58%, paper bags, carlots	ton	146.00
Sodium hydroxide, tech. (caustic soda), bulk	ton	560.00
Sulfur, crude, 99.5%, 50-lb bags, mines	100 lb	13.60
Sulfuric acid, 100%, tanks, works	ton	75.00
Toluene, petroleum, indust., tanks	gal	0.76
Urea, 46% N, indust., bulk, Gulf coast	ton	210.00

Appendix F Estimating Equipment Costs by Scaling

It is necessary to estimate the cost of a piece of equipment when no cost data are available for particular size of operational capacity involved. Good results can be obtained by using the logarithmic relationship knows as the six-tenths-factor rule, if the new piece of equipment is similar to one of another capacity for which cost data are available. According to this rule, if the cost of a unit at one capacity is known, the cost of a similar unit with X times the capacity of the first is approximately $(X)^{0.6}$ time the cost of the initial unit

$$Cost\ of\ equip._f = Cost\ of\ equip._i \left(\frac{capac.\,equip._f}{capac.\,equip._i}\right)^{0.6}$$

The preceding equation indicates that a log-log plot of capacity versus equipment cost for a given type of equipment should be a straight line with a slope equal to 0.6. However, the application of the 0.6 rule of thumb for mist purchased equipment is an oversimplification of a valuable cost concept since the actual values of the cost capacity factor vary from less than 0.2 to greater than 1.0 as shown in Table F1. Thus the 0.6 factor should only be used in the absence of other information. The cost-capacity concept normally is not be used beyond range of ten times capacity, and care must be taken to make certain the two pieces of equipment are similar with regard to type of construction, materials of construction, temperature and pressure operating range, and other variables.

Ex. Cost estimation for dryer drum

The purchased cost of 2.26 m^3 dryer drum was $63,738 in Jan, 2002. Estimated cost of 0.19 m^3 dryer drum in April 2014 is determined below.

Solution Chemical Engineering Index (CE index) for Jan, 2002 = 390.4

Chemical Engineering In for April, 2014 = 573.6

From Table F1, the exponents for equipment cost vs. capacity for dryer drum is 0.40:

$$Cost_{April,2014} = Cost_{Jan,2002}\left(\frac{CE\ index_{April,2014}}{CE\ index_{Jan,2002}}\right)\left(\frac{capac.\ equip._{April,2014}}{capac.\ equip._{Jan,2002}}\right)^{0.4}$$

$$Cost_{April,2014} = \$63,738\left(\frac{573.6}{390.4}\right)\left(\frac{0.19}{2.26}\right)^{0.4}$$

$$Cost_{April,2014} = \$34,782$$

$$Cost_{April,2014} = 1,125,201.01\ Bath$$

Table F1 Typical exponents for equipment cost vs. capacity

Equipment	Site Range	Exponent
Blender, double cone rotary, C.S.	50-250 ft^3	0.49
Blower, centrifugal	10^3-10^4 ft^3/min	0.59
Centrifuge, solid bowl, C.S.	10-10^2 hp drive	0.67
Crystallizer, vacuum batch, C.S.	500-7000 ft^3	0.37
Compressor, reciprocating, air cooled, two-stage, 150 psi discharge	10-400 ft^3/min	0.69
Compressor, rotary, single-stage, sliding vane, 150 psi discharge	10^2-10^3 ft^3/min	0.79
Dryer, drum, single vacuum	10-10^2 ft^2	0.76
Dryer, drum, single atmospheric	10-10^2 ft^2	0.40
Evaporator (installed), horizontal **tank**	10^2-10^4 ft^2	0.54
Fan, centrifugal	10^3-10^4 ft^3/min	0.44
Fan, centrifugal	$2x10^4$-$7x10^4$ ft^3/min	1.17
Heat exchanger, shell and tube, floating head, C.S.	100-400 ft^2	0.60
Heat exchanger, shell and tube, fixed sheet, C.S.	100-400 ft^2	0.44
Pump, reciprocating, horizontal cast iron (includes motor)	2-100 gpm	0.34
Pump, centrifugal, horizontal, cast steel (includes motor)	10^4-10^5 gpm x psi	0.33
Reactor, glass lined, jacketed (without drive)	50-600 gal	0.54
Reactor, S.S, 300 psi	10^2-10^3 gal	0.56
Separator, centrifugal, C.S.	50-250 ft^3	0.49
Tank, flat head, C.S.	10^2-10^4 gal	0.57
Tank, C.S., glass lined	10^2-10^3 gal	0.49
Tower, C.S.	10^3-$2x10^6$ lb	0.62
Tray, bubble cup, C.S.	3-10 ft diameter	1.20
Tray, sieve, C.S.	3-10 ft diameter	0.86

Appendix G Heat Duty for Rotary Kiln Calculation

From $$Q = mC_p\Delta T$$

By $$m = \frac{500000\ \frac{g}{hr}}{174.259\ \frac{mol}{g}} = 2869.29\ \frac{mol}{hr}$$

$$C_{p,potassium\ sulfate\ (solid)} = 131.31\ \frac{J}{mol\ K},\ at\ 298\ K$$

Then $$Q = (2869.29\ \frac{mol}{hr})(131.31\ \frac{J}{mol\ K})(700 - 35\ K)$$

$$Q = 250551808\ J/hr$$

$$Q = 69.65\ kw$$

Appendix H Screw Conveyor with Water Jacket Size Calculation

The calculation is started from calculation of water flowrate. And then this factor is used to calculate to find jacket diameter.

Water flowrate calculation:

*Assume: $T_{cooling\ water\ inlet} = 25\ ^{o}C$

$T_{cooling\ water\ outlet} = 50\ ^{o}C$

$T_{product\ inlet} = 700\ ^{o}C$

$T_{product\ outlet} = 50\ ^{o}C$

From $$Q_{water} = Q_{Potassium\ sulfate}$$

Then $$m(4.2\ \frac{J}{g\ K})(50 - 25\ K) = (2869.29\ \frac{mol}{hr})(131.31\ \frac{J}{mol\ K})(700 - 50\ K)$$

$$m_{water} = 2332383\ g/hr$$

$$m_{water} = 2332383\ cm^3/hr$$

$$m_{water} = 616\ gal/hr$$

$$m_{water} = 2772000\ gal/yr$$

Screw conveyor with water jacket diameter calculation:

$$V_{jacket} = Water\ flowrate$$

$$\pi r^2_{jacket}(20\ m) = 2.33 m^3$$

$$r^2_{jacket} = 0.380\ m^2$$

$$r_{jacket} = 0.616\ m$$

So $$D_{jacket+conveyor} = 13.0\ m$$

Appendix I Sodium Hydroxide and Water for Wet Scrubber Calculation

This calculation is used to find the amount of sodium hydroxide solution (5% conc.) by using heat transfer equation.

*Assume: $C_{p,\ 5\%\ Sodium\ hydroxide} = C_{p,\ water} = 4.2\ J/(g^{o}K)$

$T_{cooling\ inlet} = 25\ ^{o}C$

$T_{cooling\ outlet} = 50\ ^{o}C$

$T_{flue\ gas\ inlet} = 700\ ^{o}C$

$T_{flue\ gas\ outlet} = 50\ ^{o}C$

From $$Q_{solution} = Q_{Potassium\ sulfate}$$

Then $$m(4.2\ \frac{J}{g\ K})(50 - 25\ K) = (2869.29\ \frac{mol}{hr})(131.31\ \frac{J}{mol\ K})(700 - 50\ K)$$

$$m_{solution} = 2332383\ g/hr$$

$$m_{solution} = 1.37\ ft^{3}/min$$

$$m_{solution} = 2772000\ gal/yr$$

So $$m_{Sodium\ hydroxide} = 2772000\frac{gal}{yr} \times 0.05 = 138600\ gal/yr$$

$$m_{Water} = 2772000\frac{gal}{yr} \times 0.95 = 2633400\ gal/yr$$

Appendix J Feed and Water Flowrate Required for Extraction and Precipitation Calculation

This calculation is used to determine the flowrate of solid waste and water which used to solute biodiesel solid waste.

Feed flowrate calculation:

Salt requires	6.34 g	Feed requires	6.84 g
Then: Salt requires	500 kg/hr	Feed requires	539.43 kg/hr

*Potassium sulfate density = 2660 kg/m^3

Feed flowrate = 539.43 kg/hr = 0.20 m^3/hr

Water flowrate calculation

Feed requires	6.84 g	Water requires	50 ml
Then: Feed requires	539.43 kg/hr	Water requires	3943.20 ml/hr

Water flowrate = 3943.20 ml/hr = 0.004 m^3/hr = 4756 gal/yr

Appendix K Storage Capacity Calculation

Assume: Storage are designed for 3 months stock and increased more 30 % of capacity in case of safety.

Table K1 Storage capacity of each utilities for combustion process

	3 months cap. (m^3)	Stock (m^3)
Water	2492.73	3240.56
NaOH Solution	124.64	162.03
LPG	101.81	132.35

Table K2 Storage capacity of each utilities for extraction and precipitation process

	3 months cap. (m^3)	Stock (m^3)
Water	4.5	5.85
EtOH	4.5	5.85

Appendix L Product Price Calculation

This section is shows the method to calculate product price from the process.

Ex. Product price calculation for combustion process

From $$Product\ price = \frac{Total\ production\ cost}{Production\ rate}$$

By $$Total\ production\ cost = 12{,}485{,}342\ Bath/yr$$

$$Production\ rate = 2{,}250{,}000\ kg/yr$$

Then $$Product\ price = \frac{12{,}845{,}342\ {}^{bath}/_{yr}}{2{,}250{,}000\ {}^{kg}/_{yr}}$$

$$Product\ price = 5.55\ {}^{bath}/_{kg}$$

Appendix M Payback Period Calculation

This section is shows the method to calculate payback period from the process.

Ex. Payback period calculation from combustion process

Net profit calculation

*Assume: Product sale price = 15 bath/kg

From $Net\ profit = Product\ sale - Total\ production\ cost$

By $Total\ production\ cost = 12485342\ bath/yr$

$$Product\ sale = \left(15\frac{bath}{kg}\right)\left(2250000\ {}^{kg}/_{yr}\right) = 33750000\ {}^{bath}/_{yr}$$

Then $Net\ profit = 33750000\ {}^{bath}/_{yr} - 12845342\ {}^{bath}/_{yr}$

$Net\ profit = 21264658\ {}^{bath}/_{yr}$

From $Payback\ period = \frac{Capital\ cost}{Net\ profit}$

By $Total\ capital\ cost = 41102234\ bath$

Then $Payback\ period = \frac{41102234\ bath}{21264658\ {}^{bath}/_{yr}}$

$Payback\ period = 1.93\ yr$

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2012-2013 Position: Sales Engineer

Company name: M-Wave Marketing

Presentation:

1. Nachawon, P.; and Boonyarach, K. (2015, April 21) Separation of organic and inorganic compounds in solid waste obtained biodiesel production process. Proceedings of The 21st PPC Symposium on Petroleum, Petrochemicals, and Polymers 2015, Bangkok, Thailand.