"DESIGNING TO REMOVE PHOSPHORUS BY USING METAL SALTS AND POLYMERS IN CONVENTIONAL PLANTS"

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Note: This discussion guide supplements material in "Process Design Manual For Phosphorus Removal". That manual is listed (1) among references cited here.

1. What is covered here - and why?
   a. Discussion covers use of metal salts and polymers in otherwise conventional plants. Tertiary systems are not included.
   b. Recent reports (2) (3) (4) (5) (6) (7) show progress has occurred.
   c. Designers can - and must - proceed with positive pragmatism.
   d. Material is based on fundamentals proven in plant scale operations.
   e. Operational aspects are included, and deserve design emphasis.
   f. Designers must be part of startup and initial operations.
2. Should you use these processes? When and Where:
   a. Ignoring "the great P debate" (8) (9) (10), are these processes attractive? Local quality standards yield the answer. Concurrent improvement in BOD and suspended solids may be key factors.
   b. Modification of existing plants is usually simple, and inclusion in new plants is minor. Capital costs are quite low.
   c. Degree of treatment dilemma: going from 80% to 95% phosphorus removal may increase operation costs 50% or more. However, the physical facilities are identical in either case and operational flexibility allows choice at later time.
   d. Owner's decision should be carefully made. Reduction in suspended solids and BOD may be pivotal. Success demands his commitment to:

...intelligent 24-hr. operation (does not mean 3 men)

...lab support beyond conventional plant operations

...total cost increase of 7¢ or 8¢/1000 gal (chemicals are 5¢ of this).

3. Points of application: several possibilities lead to one clear choice

a. Primary clarifier ...greatest sludge yield of any variation, but substantial reduction of subsequent biological sludge

...escaping colloids are reduced in following units

...lowest ortho-P fraction

...50% BOD reduction appeals in overloaded plant.

b. Biological unit ...trickling filter may blotch and slough but won't plug. However, not an effective point of application. Offers no advantages over other choices.

...contact stabilization modification proposed (11)

...MLSS provide great sorptive area and bioflocculation reduces amount of chemical required

...aeration tanks afford flocculation and detention; can add at middle or near end, but enroute to final clarifier is most popular

...effect of metals on MLSS biota still unclear (12) but apparently not detrimental

...large MLSS floc may agglomerate and this could reduce exposure of active biota and impede transfer of oxygen, offgases, and substrate

...nitrification may be suppressed by pH shock.

c. Final Clarifier ...loss of control here means poor effluent in a hurry; but quite effective and reliable in practice

...stearic hindrance of detergents reduced here

...ortho-P predominates, and is desired form

...underflow stimulates primary settling if returned there in trickling filter plant

...activated sludge unit has far more solids handling capacity, but has more load too

...fairly high chemical demand because must add enough to complete precipitation, coagulation and glue suspended solids together.

d. Multipoint facilities: inexpensive approach to effective performance

...allows total feed to any of several points

...permits split feed, a popular approach at several plants.

4. Trial efforts: How big and how long? A bold approach is justified

a. Jar test (13) ...a vital but treacherous ally

...auxiliary flash mix for thorough dispersal

...stator is key accessory, an assembly of plastic fins

...hydraulic similitude by eyeball (stare at plant unit then adjust jar turbulence to match)

...assume plug flow in setting agitation times in jars

...dynamic "settling" is a must (5-8 rpm)

...practice, practice, practice.

b. Other lab tests work (14) (15) but dawn comes slowly at "the sewer plant".

c. Pilot facilities: an exercise in futility due to cost, operational vagaries, and the perfidious scale factor.

d. Full plant (or isolated module) trial: going in style, with confidence, without going broke. Fig. 1: typical 1.6 MGD plant in Richardson, Texas (16).

5. Chemicals: who are they, what do they do, and how?

a. Available forms (17)

Metal salts:	FeCl , pickle liquor, alum, and sodium aluminate (which also provides alkalinity)... liquids are best (cost, effectiveness, flexibility, ease of handling)
Polymers:	most come dry; no universal choice; 3 categories

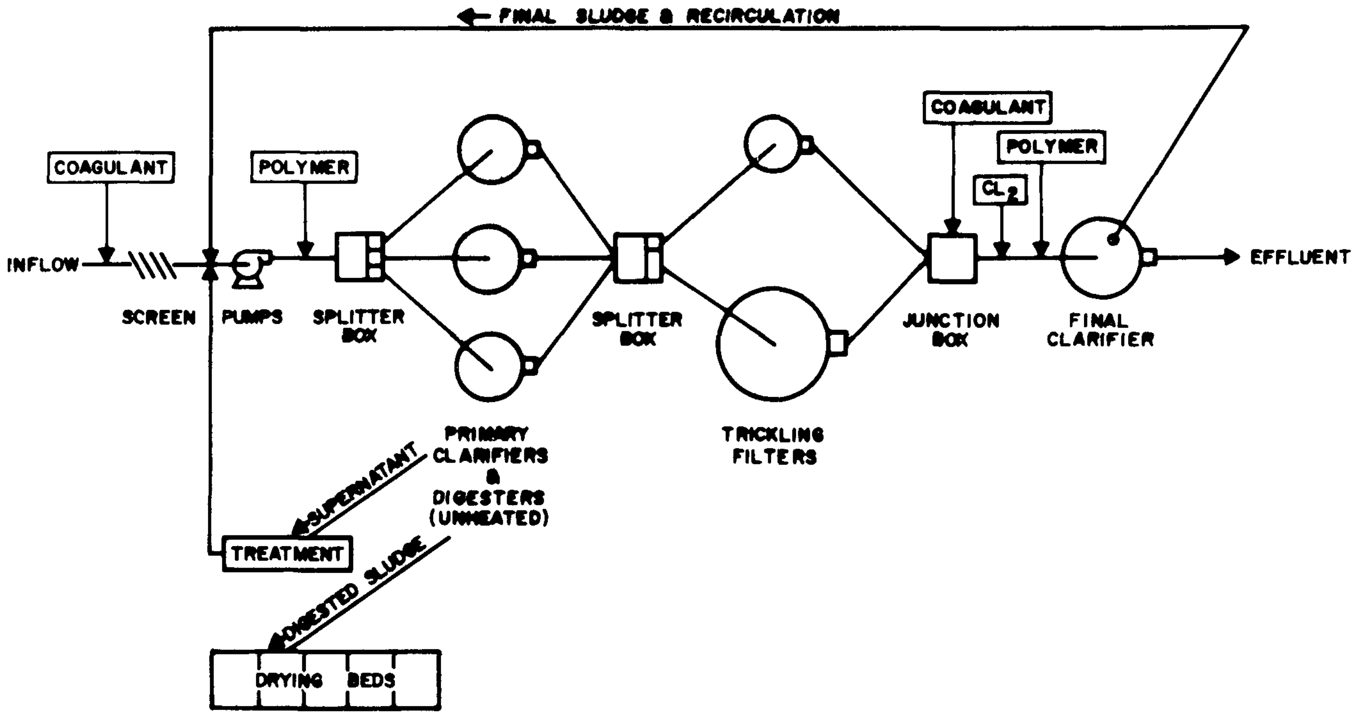
b. Technical Details on Coagulants

...alum (48.5% soln of filter alum is 8.25% aluminum oxide) weighs 11.1 lb/gal, and 4.37% of this is available aluminum

...sodium aluminate (46% soln) is 15.1% Al by weight, but different suppliers offer different concentrations

...ferric chloride varies from 35% to 45% soln, according to weather (agitated 45% soln freezes at 45°F, and 37% soln at 15°F); 40% soln weighs 11.9 lb/gal, and 16.4% of that is iron

...see manufacturers' technical bulletins for complete details on all coagulants and polymers.



	Diam (Ft)	Depth (Ft)	Circum (Ft)	Area (Sq Ft)	Volume (Cu Ft)	Volume (Gal)
Primary Clarifier No. 1	40	8	126	1257	10,054	75,200
2	40	10	126	1257	12,570	94,000
3	40	10	126	1257	12,570	94,000
All Primary Clarifiers	--	--	378	3771	35,194	263,200
Final Clarifier	70	6	220	3848	23,088	173,000
Filter No. 1	84	6.5	---	5542 (1)	36,000	---
2	120	6.5	---	11310 (1)	73,500	---
Filters Combined	---	---	---	16852 (1)	109,500	---
Digester No. 1	40	14.3 (2)	---	1257	13,000	135,000
2	40	14.3 (2)	---	1257	13,000	135,000
3	40	14.3 (2)	---	1257	13,000	135,000
Digesters Combined	--	---	---	---	39,000	404,000

Sludge Drying Beds 12,000 Square Feet

(1) Area in acres: 0.127, 0.260 and 0.387, respectively
(2) 14.3 Effecitve, 18.0 SWD, 15.8 Clear @ Center

I TREATMENT PLANT WITH CHEMICAL PRECIPITATION FACILITIES (REF 12)

c. Three key functions involved in mineral addition:

...Precipitation of ortho-P to insoluble colloid

...coagulation (destabilization) of all colloids

...flocculation (agglomeration) of destabilized colloids

d. Precipitation: reactions and kinetics (18)

...solely by metal salts

...produces metal phosphates, of some sort (19) (20)

...fast, essentially complete in one second

...pH will be depressed; 6.5 good value, but watch to see alkalinity in effluent is 50 mg/l

...polyelectrolytes not involved, defer their addition.

e. Coagulation: reactions and kinetics (21)

...key developments in coagulation: reduction of surface charge on hydrophobes, dehydration of water layer on hydrophyls (same as water treatment)

...coagulation competes with P-precipitation for metal species

...metal coagulation very rapid: one second

...metal radicals are complicated, probably polymerize into complicated transient forms (22)

...polymer coagulation less rapid: seconds to minutes, and it should not be started until metal reaction is through; allow lag time of 2 to 5 minutes

...homegrown polymers have obscure role (23) (24) they are generated during biological treatment.

f. Flocculation: reactions and kinetics

...flocculation proceeds languidly thru decreasing energy levels over a period of minutes; involves both metals and polys; we can see it occur

...key developments in flocculation: glue colloids together at moment of collision, provide skeleton for dense floc, act as broomstraws for sweeping up surviving colloids.

g. Physical arrangments inferred:

...flash mix intensely for 1-30 seconds (adding metal salt)

...high energy flocculation 1-5 minutes (add polys near midpoint)

...low energy flocculation 5-20 minutes

...facility requirements are modest, largely inherent in conventional existing plant.

6. Hardware: type, size, location and use (25)

a. Storage tanks

...fiberglass (filament wound or layup) from good supplier, exceeding minimum standards (26) (27)

...natural amber, or colored tanks are attractive

...coagulant: size for 7-10 day supply on 2/1 mole ratio; approx 400 gal/MGD/day for alum (equals 3 weeks for FeCl or aluminate); 6000 gal tank will accept 5000 gal tank truck lots

...tank hardware: strip or float gauge, mansized manhole, fill inlet with snap coupling, pump suction, vent, flush-bottom drain

...use one-inch thick polyurethane pad between slab and tank, unless weather dictates heated pad to keep coagulant warm

...polymer: size for 2-3 day supply of 0.5% soln; this is 400 gal/MGD at 2 mg/l dose. Can always dilute below 0.5% and will probably want to

...same tank fittings as coagulant, plus overpowered mixer for 1000 cp viscosity; fill inlet connects to water; disperser funnel also requires water

..consider shelter for polymer units; operators appreciate this

...auto poly dispersers available and have been successfully used at two dozen plants; check with equipment vendors (28) (29) (30) (31)

b. Piping

...PVC or FRP, protected from freezing as required

...provide flushing tees following pumps

...accumulators not necessary; manual air blowoffs recommended at high points in line (using 3-way valve, these make good sampling-calibrating ports)

...put strainers on pump suctions, and make lines big and well-reinforced against physical abuse

...dilute poly pump discharge with about 20 gpm water, followed by at least 50-ft run of pipe; use jet or turbulence section if pipe run is too short.

c. Feeding equipment

...many types of variable discharge positive displacement pumps can serve: diaphram, plunger, gear, progressing cavity

...proper selection of pump materials allows interchange between coagulant and polymer service

...use pumps designed for 500 psi service, put in a 40 psi backpressure valve and neglect head loss in piping that follows

...backpressure seats check valves to improve accuracy; double check valves are good

...don't select too large a pump: low-range control difficult; some pumps have interchangeable heads of different sizes

...ratio control helpful, in addition to percent output control

...no problems in calibration and recalibration; pump water for original curve, then chemical solution

...pumpage record often based on operator's log

...Fig 2: another approach: gravity flow; use mag meter, T-I-R and air or electric throttling valve

...Fig 3: any system should include or adapt to auto control; can go as far as compound loop system--

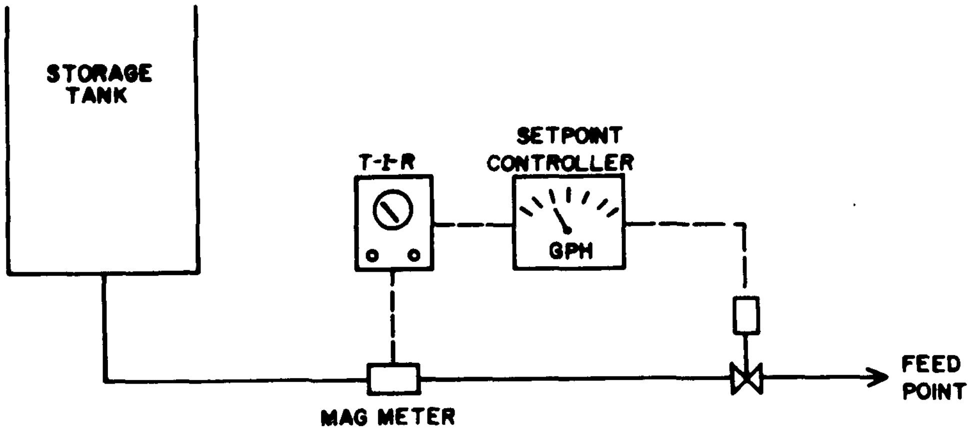


FIG 2 GRAVITY CHEMICAL FEED SYSTEM

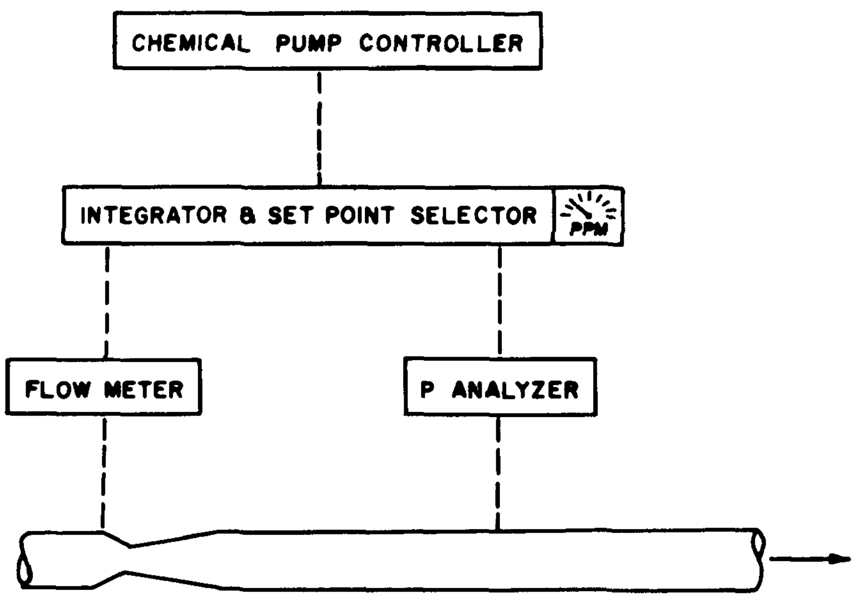


FIG 3 CHEMICAL FEED CONTROL BY COMPOUND LOOP

if reliable P-analyzer is included; figure shows "feed forward" system where effluent monitoring can be used to trim base dose.

...include hose stations for washdown of spillage, plus service as emergency shower and eye fountain

d. Chemical injection: two chemicals and two exhortations

...Coagulant: inject full strength (to prevent premature hydrolysis) into intense dispersion zone, with one inlet pipe per mixing unit up to 8-10 MGD; current unpublished work may open trend to controlled predilution to enhance flash mix operation (32) but this practice not yet established

...Polymer: have several inlet points available, injecting a diluted stream (multiport or header device above 3 MGD). Aim for thorough dispersion at moderate energy levels.

e. Flash mixing: our most grevious shortcoming (33) (34)

...raw inflow requires hydraulic jump, drop box, drop manhole, air agitation, or pump discharge; all relatively unsatisfactory due to low energy levels

...with treated flow, use propeller or turbine mixer, vortex unit, jet, or other devices (35) (36) (37). Inline approach is excellent. Baffled basin is poor choice

...Gt has little value; G is suspect because it does not measure local intensity but use it anyway, supplying an input of 800-1000 for up to 30 seconds. Be prepared to adjust hardware (baffles, etc.)

...for electrically driven mechanical mixer, calculate:

$G = \sqrt{(WHP) \quad (550) \; / \; (u) \quad (V)}$, where

(WHP) is delivered water horsepower or

(KVA) (Mtr Eff) (Pwr Factor)/(0.746)

(u) is absolute viscosity, (2 x 10) (exp-5) at 70°F

(V) is mixed volume in cubic feet

...analyzing a baffled basin (or other head loss unit) for G:

$G = \sqrt{(62.4) \quad (H) \; / \; (T) \quad (u)}$, where

H = head loss thru basin; one foot for example

T = detention time; 31.2 seconds for example

u = absolute viscosity; (2 x 10) (exp-5)

$= \sqrt{(62.4) \quad (1.0) \; / \; (31.2) \quad (0.2 \times 10) \quad (exp-5)}$

= (316 sec) (exp-1)

but (1) G value of 316 less than 800-1000 recommended

(2) Introduction of energy over a 31-second period is inefficient when chemical reactions are complete in 5% of that time

(3) In a drop box detaining flow for 3.12 seconds, G becomes 1000. Required volume

of 4.5 Cu Ft/MGD (a cube with 20-inch edges) presents design challenge.

...proper mix in aeration basin is problematical; just put chemical in and see how it works. Cannot analyze for G value because bubble energy not totally spent within the hydraulic system

...in an open flash mix box, mix at front end and leave at least threefold following volume for future needs (e.g. controlled high energy flocculation); Fig. 4: junction box can be modified to serve.

f. Flocculation: Special mechanisms and tankage not needed; use water plant technology for analysis (38) (39) (40)

...high energy flocculation occurs in effluent end of mix unit, pipe, and clarifier centerwell (or equivalent); energy level is declining; clarifier inlet hydraulics are critical

...low energy flocculation occurs in blanket near clarifier inlet; donut may be extensive with activated sludge; extra baffle may be needed

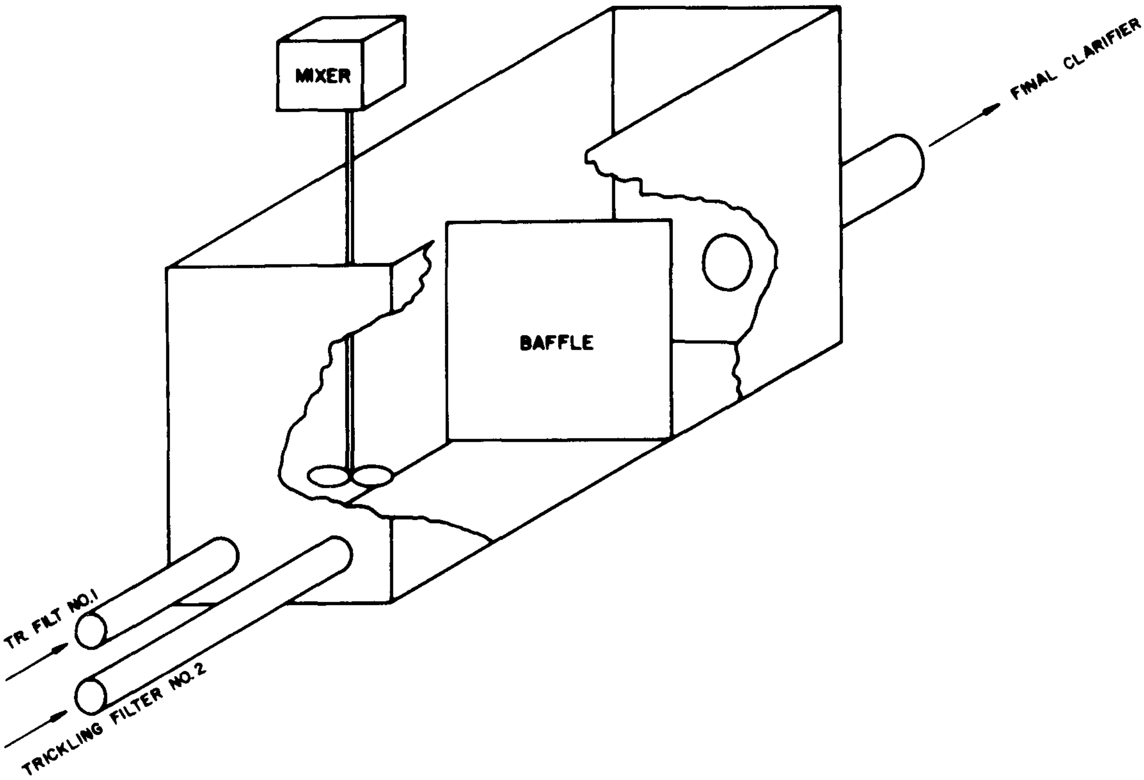
...can flocculate in last section of activated sludge aeration tank, and in pipe and clarifier inlet which follow.

7. Dosage selection and control: key to success

a. Coagulant: here is where the money and performance are

...key parameters: mole ratio fed, and effluent P

...generally primary addition requires more than final



Flow Rates		Coagulation	Flocculation Time (Minutes)		
MGD	GPM	(Minutes)	High Energy	Low Energy	Total
1	700	1.42	5.71	28.6	34.3
1.5	1,050	0.95	3.81	19.1	22.8
2	1,400	0.71	2.86	14.3	17.1
2.5	1,750	0.57	2.28	11.4	13.7
3	2,100	0.48	1.91	9.5	11.4

FIG 4 JUNCTION BOX MODIFIED TO FLASH MIX (REF 12)

clarifier, which requires more than aeration tank; these variations in demand relate to coagulation because precipitation demand is relatively constant

...Fig. 5: assess P income both on hourly and daily composite basis; if serving urban or suburban areas, expect high P income on Saturday, low on Sunday, typical on weekdays

...convert lb/day to lb-mole/day; set mole ratio at 2/1 or 1.5/1; factors are 31 for P, 27 for Al, and 56 for Fe; typical calculation would be:

If Phosphorus Income (As P) is 310 lb/day:

310/31 = 10 lb-moles/day

If Desired Mole Ratio (M/P) is 2/1:

(2/1) (10) = 20 lb-moles metal required

Using Liquid Alum:

(20) (27) = 540 lb Al required

(540) / (11.1 lb/gal) (4.37% Al)

= 1100 gal liquid alum required

...dose rate should be varied 3-5 times per day to meet P income at point of feeding; this is critical

...cam regulated feed control is attractive (41) (42)

...Figs. 6-7: plot effluent P to see if peaks occur, adjust feed to correct; don't overcompensate

...Fig. 8: keep varying coagulant feed until reaching desired P removal; stay on a given schedule at least 5 days (giving scant weight to the first).

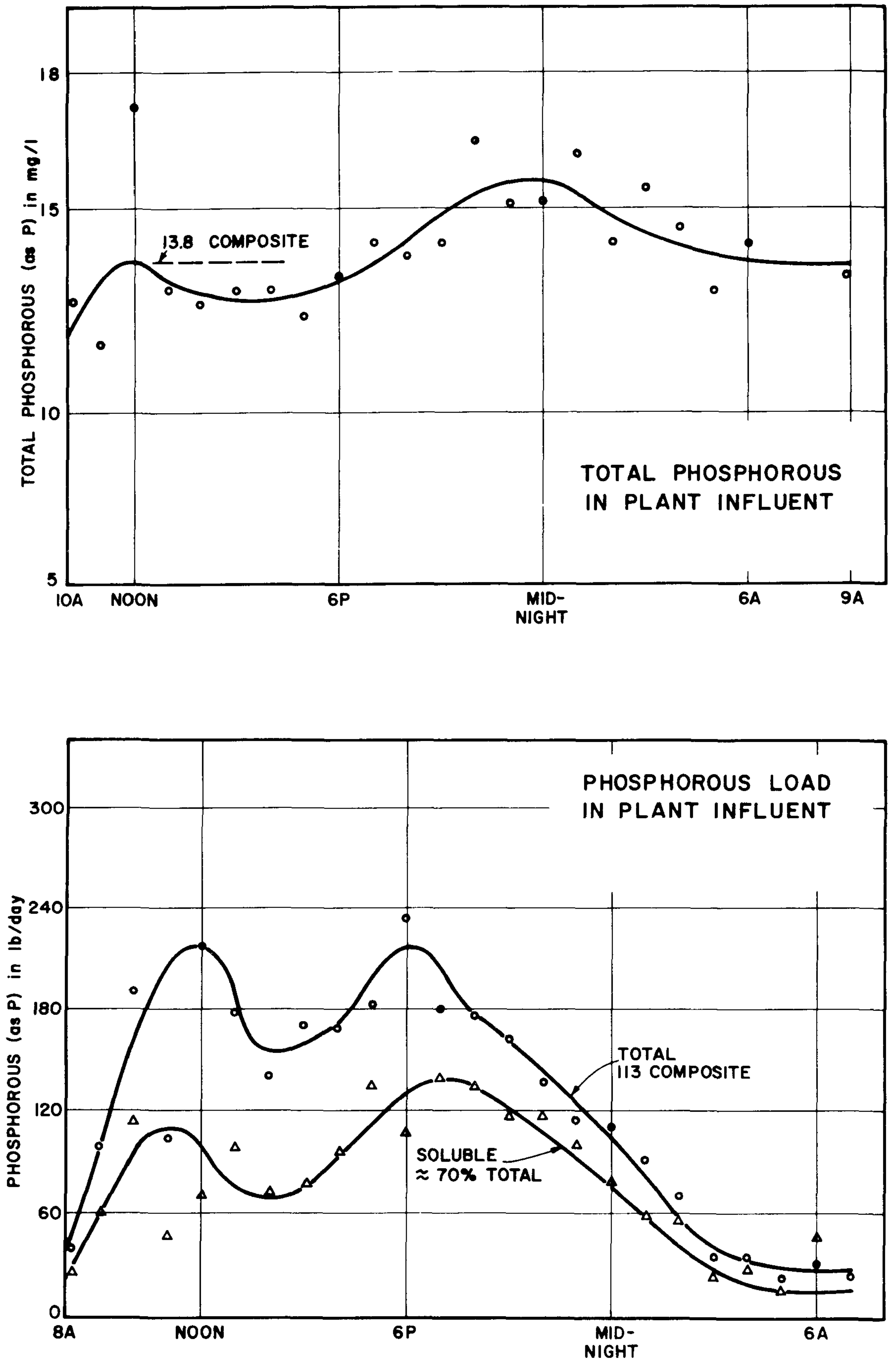


FIG 5 PHOSPHOROUS INCOME PLOTS (REF 12)

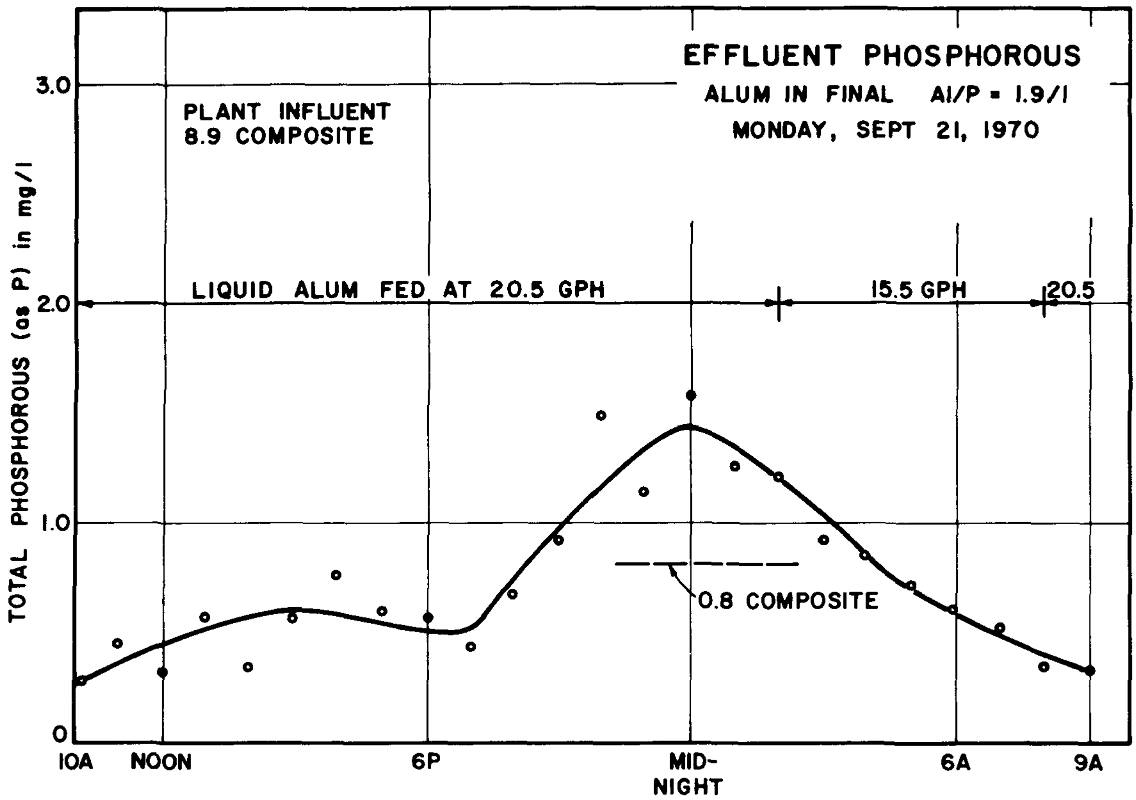


FIG 6 TOO FEW CHEMICAL PUMP SETTINGS GIVE POOR CONTROL (REF 12)

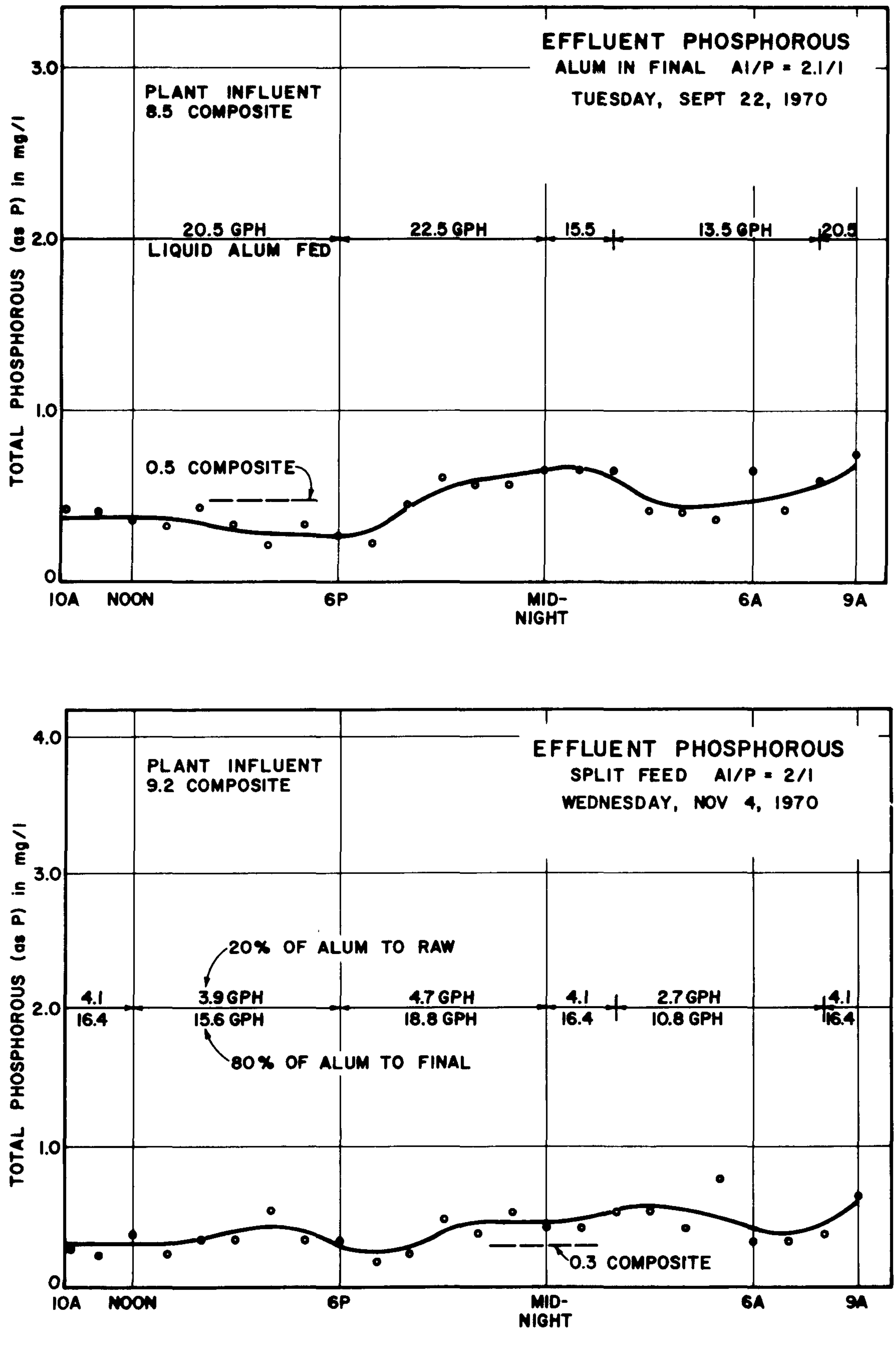


FIG 7 REFINED FEED ADJUSTMENT IMPROVES RESULTS (REF 12)

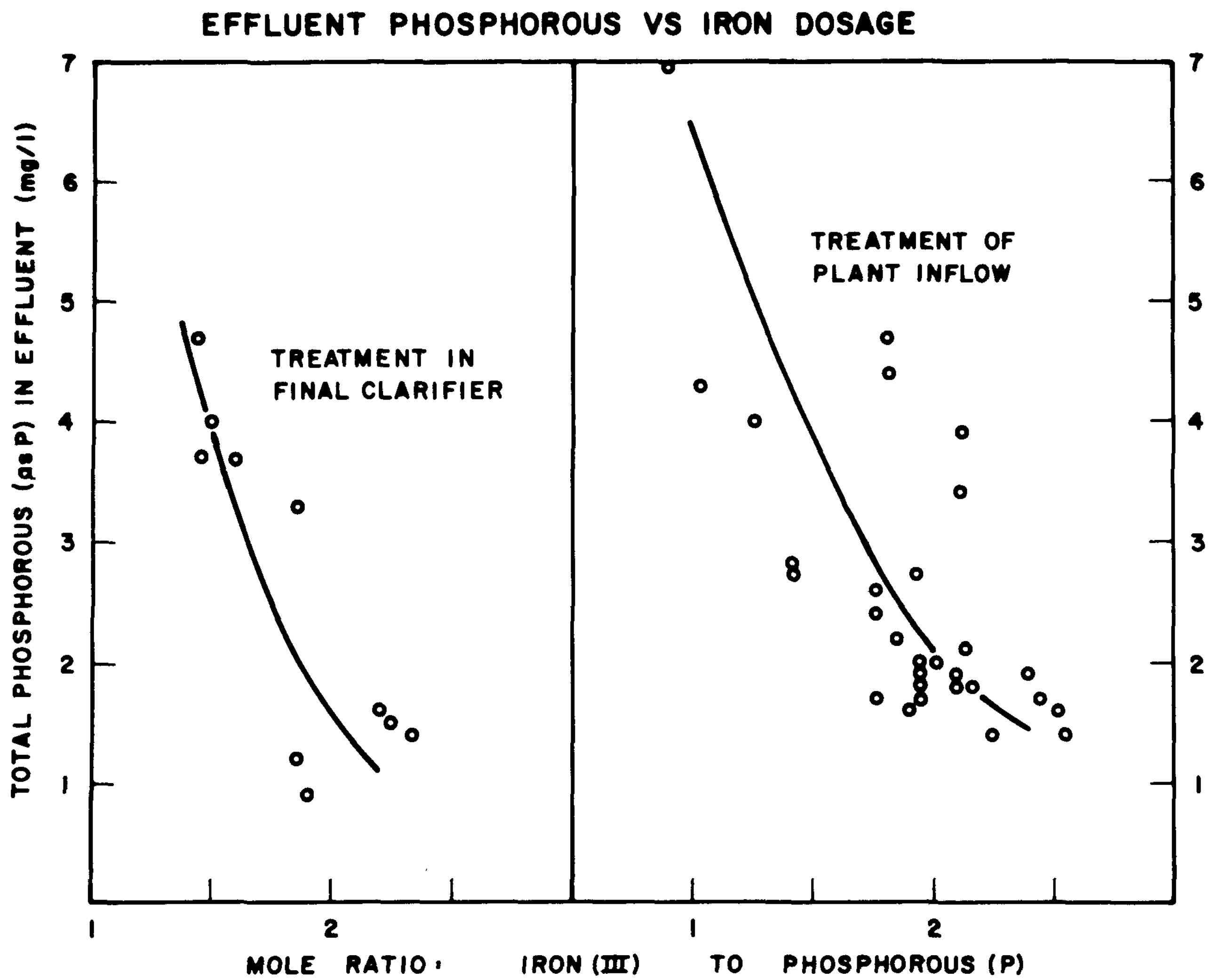


FIG. 8 STUDY OF RESULTS ALLOWS SELECTION OF DESIRED MOLE RATIO

b. **Polymer:** usually improves solids capture; may reduce metal salt demand enough to be economically attractive

...jar test several, then try in plant

...typical dose is less than one mg/l

...proper dose and dispersion: "slick fingers" test (slippery feel to effluent) means overdose or poor dispersion or both

...turbidity, by eye or instrument, is good test

...feed rate is sometimes constant, perhaps reduced at night or interlocked with rate of wastewater flow.

c. Sampling and analysis: clear some space in the lab, Fig. 9

...analyses for conventional treatment are continued

...coagulant analysis involves both anion and cation

...alkalinity is optional, unless effluent level drops to 50 mg/l

...turbidity of final effluent is good test; lab unit or submerged disc

...observation of clarifier blanket is good control tool

...P analysis can be automated; daily composite also required, and is main test in stable operation.

8. Sludge harvesting and disposal

a. Clarifiers: make it drop like a rock--and stay there

...be conservative in design: min 9-ft SWD for trickling filter plant, 12-ft for activated

ANALYSES FOR CONVENTIONAL TREATMENT

	RAW	PRIM EFF	FILT EFF	FINAL EFF	RECIRC	SLUDGE	SUPERNAT
FLOW	●				●	●	●
TOT SOL	●	●	●	●	●	●	●
TOT VOL SOL	●	●	●	●	●	●	●
SUS SOL	●	●	●	●	●		●
SUS VOL SOL	●	●	●	●	●		●
SET SOL	●	●	●	●			
BOD	●	●		●			●
DO	●			●			
COD	●	●	●	●	●		●
PH	●	●	●	●		●	●
TEMP	●	●	●	●		●	●

ADDITIONAL ANALYSES FOR CHEMICAL TREATMENT

	RAW	PRIM EFF	FILT EFF	FINAL EFF	RECIRC	SLUDGE	SUPERNAT
PHOS	●	●		●	●	●	●
ALK	●	●		●		●	●
FE	●	●		●	●	●	●
AL	●	●		●	●	●	●
SO4	●	●	●	●		●	●
CL	●	●		●			
TURB	●	●		●			

FIG 9 CHEMICAL PRECIPITATION INVOLVES ADDED LABORATORY ANALYSES

sludge, 500 or 600 gpd/SF based on average flow; 900 to 1100 gpd/SF on peak flow; good inlet system is important (try reaction jets or energy dissipating centerwells); tube settlers are working well

...preserve blanket, if possible, to serve as solids contact process; keep recirculation low in trickling filter plant; in activated sludge, have rapid sludge removal capability but throttle down as much as possible.

...floc is a good tracer, can indicate modifications

...modification can improve existing units (43).

b. Sludge treatment and disposal: the ever-present residue, but twice as much?

...expect good digestion, good gas production

...amt additional sludge depends on operation percent solids should be higher than conventional; will probably gravity thicken better, but treat thickner overflow with suspicion; sludge volume can vary from slightly less than to double previous volume

...typical weight (lb/million gal) when treating in aeration tank or final clarifier:

	Act.Sl.	HRTF	SRTF
Primary Sludge	1000	1000	1000
Biological Sludge	1000	500	100
Chemical Sludge	500	500	500
Increase from chemical	25%	33%	50%

...when treating in primary clarifier expect:
50% more total pounds in activated sludge (with less secondary sludge), and 75% more total pounds in trickling filter plant

...be courageous with digesters (often over-designed or underoperated anyway); provide heat and mix; consider thickening but treat overflow suspiciously; P will stay bound in sludge but supernatant will include colloidal P; consider operation toward high-rate range

...chemical cost for vacuum filter or centrifuge should be reduced in raw or digested sludge dewatering

...on drying beds: Fe sludge does better than Al which does better than conventional; drying time may be halved; don't draw beds too deep, and replace sand attrition for clear sweet underflow

9. Supernatant, Rogue Pollution, and other happy thoughts

a. Simple supernatant system--that works

...fill-and-draw tanks; can be modified for continuous service

...Al/P dosage of 2/1, plus 20 minutes air, then settle

...draw sludge to beds or digesters; return clear water to head of plant

...coagulant costs 0.2¢/1000 gal total plant flow

...lime may permit some ammonia stripping.

b. Iron leakage: a new form of pollution, especially in trickling filter plants

...Fig. 10: treating in final is worst

...polymer reduces escaping colloids

...Figs. 11-12: iron is reduced thru plant, when added in primary.

c. Other radicals may be pollutants too; impact depends on local situation

...one pound Al (III) as alum adds 5.35 lb sulfate

...one pound Al (III) as aluminate adds 0.85 lb sodium

...one pound Fe (II) as chloride adds 1.26 lb chloride

...one pound Fe (III) as chloride adds 1.91 lb chloride

...one pound Fe (II) as sulfate adds 1.72 lb sulfate

...one pound Fe (III) as sulfate adds 2.58 lb sulfate

10. Costs

a. Capital investment: \$3 to \$5 to \$7/capita, or about 2¢/1000 gal

...FRP tanks: \$1/gal up to 1000; 60¢/gal above 1000

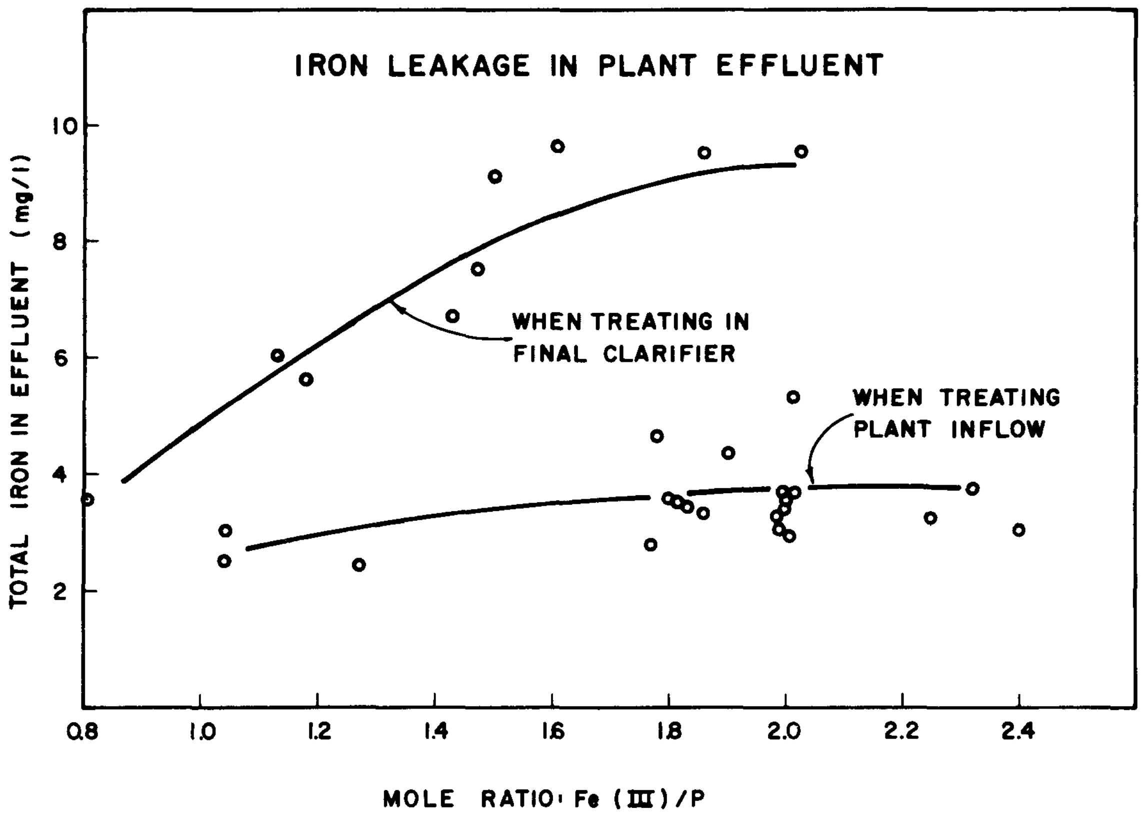
...pipe, ftngs, vlvs: \$1000/MGD (don't scrimp here)

...3 HP mixer w/starter: \$1000

...auto poly dispenser system: \$5000

...chemical pumps w/starters and auto capability: \$1500

...concrete, baffles, samplers, lab equip, auto



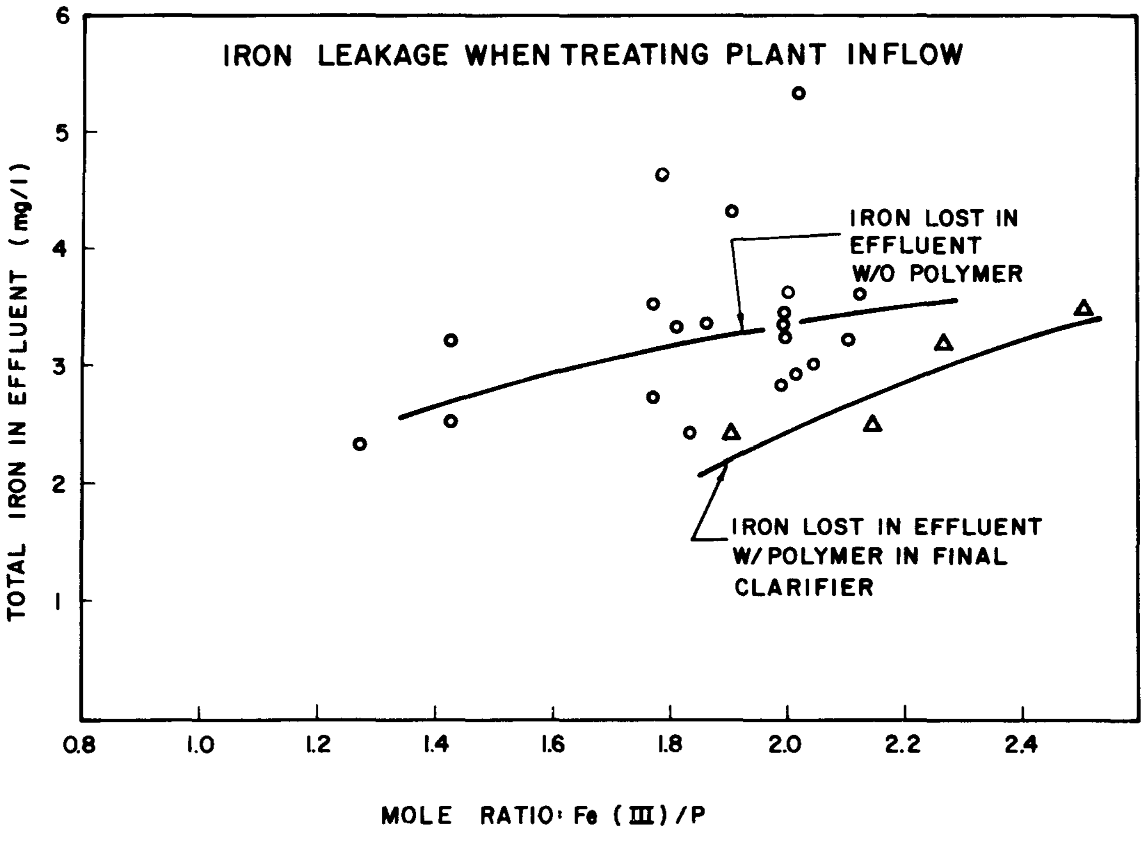
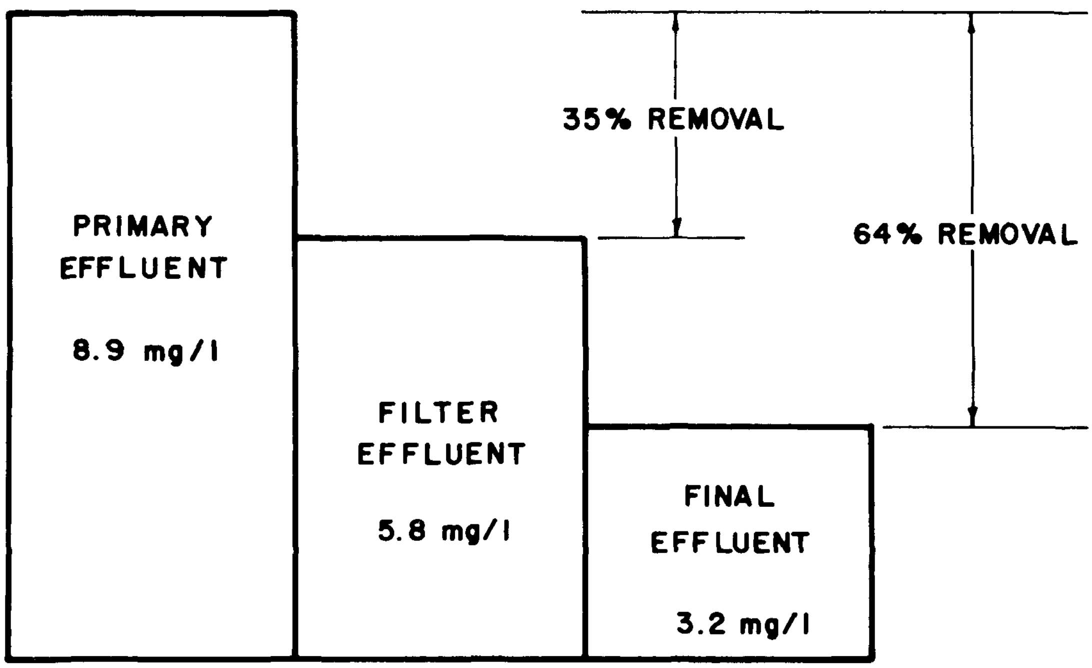
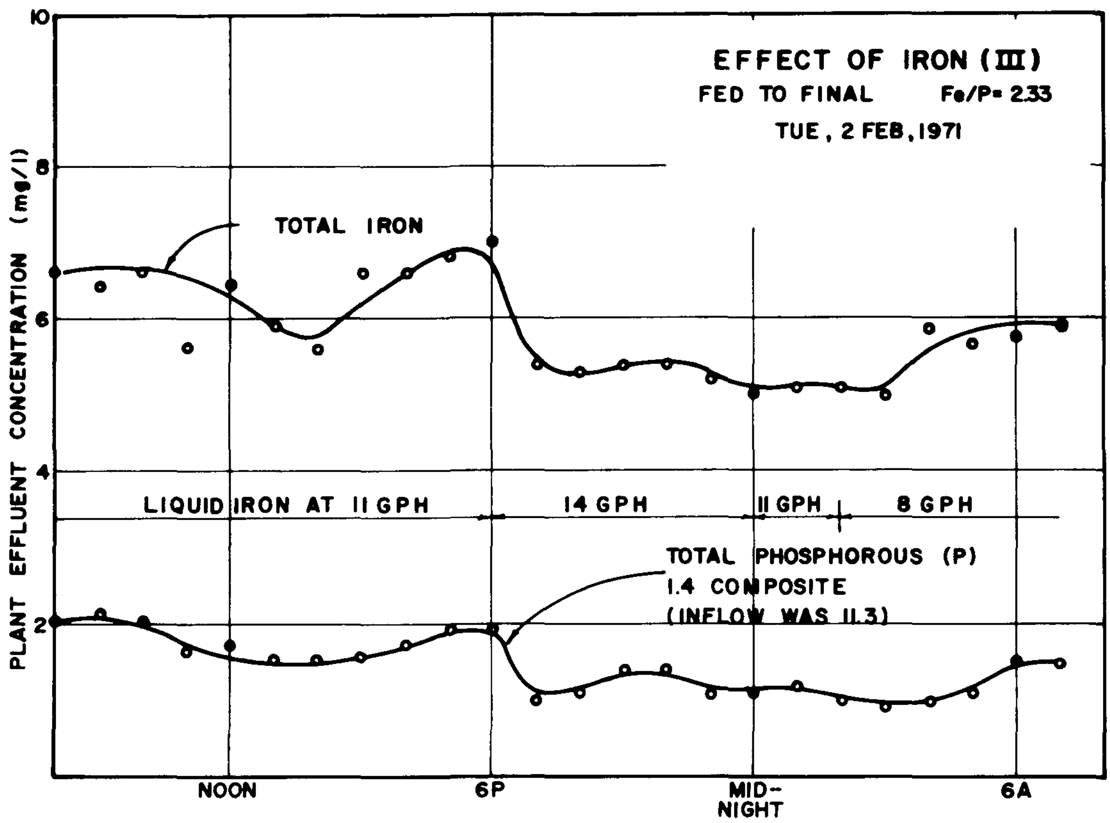


FIG 10 IRON LEAKAGE MAY BE A PROBLEM, POLYMER CAN HELP



IRON (III) LEVELS WITHIN PLANT
DURING TREATMENT IN PRIMARY CLARIFIERS
PLANT INFLOW = 0.85 mg/l Feb 10-Mar 9, 1971

FIG 11 IRON REMOVAL WHEN FEEDING $FeCl_3$ TO PRIMARY (REF 12)



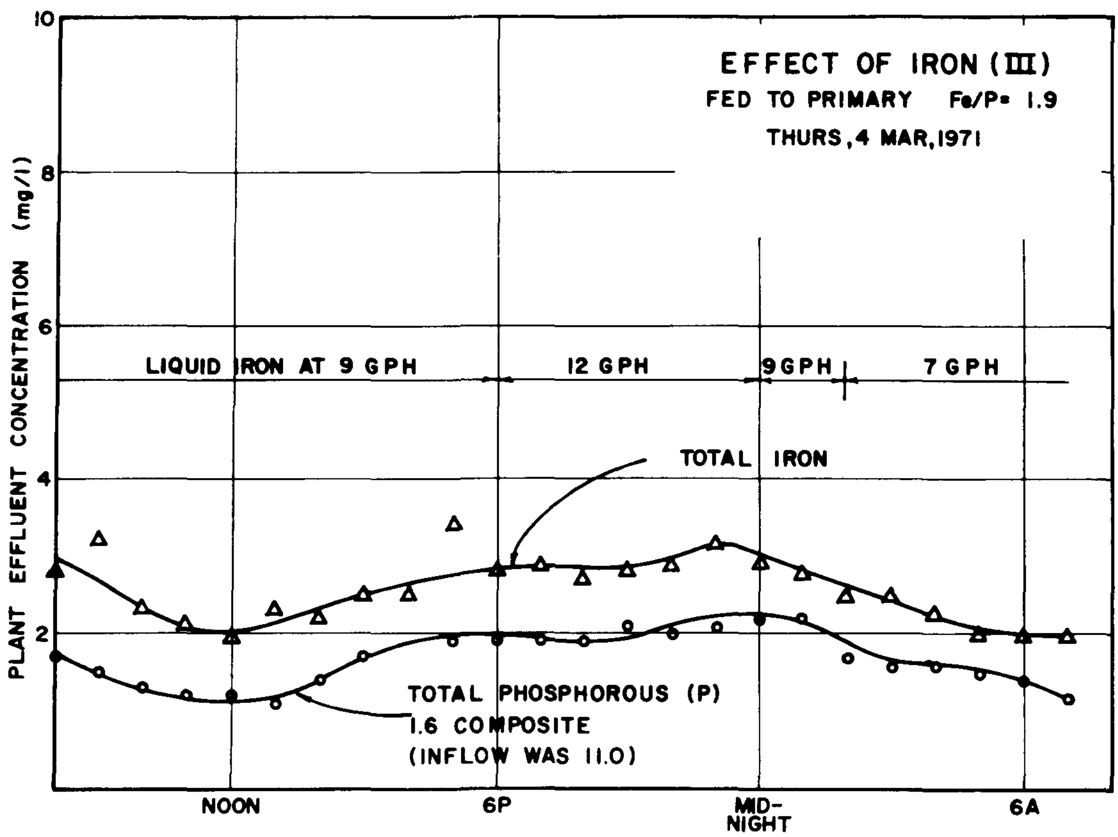


FIG 12 IRON MAY PERFORM BEST IN PRIMARY (REF 12)

controls, electric gear, shelter, etc.: estimate according to situation

...ratio of material/labor is high in these facilities

...capital costs are small part of total

b. Chemical costs: here's where the money is

...liquid alum (48.5% soln) at 24¢/lb Al; add freight (12¢/lb Al is typical for 250 miles); sodium aluminate costs near 35¢/lb Al, it includes alkalinity

...ferric chloride approx 12¢/lb Fe, plus freight (5¢/lb Fe typical for 250 miles)

...spent pickle liquor: anybody's guess

...cost = (P income) x (mole ratio for desired performance) x (unit cost)

...poly varies widely, 1¢/1000 gal is typical upper limit.

c. Other costs

...additional sludge handling @ about 1¢/1000 gal sewage

...power is nominal, about $200/yr/MGD

manpower: 24-hr intelligent operation (naturally this could be a major item in some cases); however, no additional operators are needed above those required for conventional plant

...lab support: If no analyst is planned, one should be; one can handle chemical treatment tests along with conventional analyses.

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