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Wilputte Ammonia Removal Facility Operation Manual
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INDEX

1.0 INTRODUCTION

The Ammonia Removal Facility was installed to remove the gaseous ammonia (NH_3) from the coke oven gas produced in the coke battery.

The removal is achieved by passing the coke oven gas through an ammonia absorber in which the gas is sprayed with a sulfuric acid (H_2SO_4) solution. The sulfuric acid reacts chemically with the ammonia in the gas to form ammonium sulphate $(NH_4)_2SO_4$ which remains in solution with the sulfuric acid circulating through the absorber.

Over the 20 hour cycle, the acid circulating tank in operation becomes filled with a solution of H_2SO_4 containing about 39% (by weight) of ammonium sulphate. At this stage, the residual acid is neutralized with the injection of aqueous ammonia. The tank contents are then transferred by pump to a loading out tank from where it is loaded out for sale. A standby circulating tank is brought into operation to ensure that removal of the gaseous ammonia from the gas is virtually continuous.

2.0 GENERAL DESCRIPTION OF PROCESS

Refer to the Piping and Instrumentation (P&I) diagrams #C7541 and C7542 in Section 8.0. The process line drawing in Section 9.1 provides a summary of the process flows and temperatures.

Coke oven gas at a temperature of 140°F and a pressure of approximately 50 in. w.g. enters the bottom of the gas absorber and rises through it against a descending spray of 4% sulfuric acid in 4 separate spray stages. The coke oven gas then passes into the enlarged upper portion of the absorber which has a greater cross-sectional area to permit the acid droplets carried forward from the sprays to fall out before the gas goes forward to the secondary gas cooler. An entrainment arrestor is provided in the absorber to further prevent the carryover of acid droplets. The entrainment arrestor is fitted with 4 water sprays to facilitate the cleaning of the arrestor in the event of blockages. These sprays are activated on an "as required" basis.

Acid Recirculating System

The circulating liquid (4% sulfuric acid/ammonium sulphate) is drawn from one of the three circulating tanks through a 10" diameter suction line to either of the two ammonium circulation pumps and fed through a 10" delivery line to the ammonia absorber. The delivery line is divided at the absorber into two lines, one 8"

2.0 GENERAL DESCRIPTION OF PROCESS (continued)

diameter line feeding the lower 3 sprays through 3-3" diameter lines, and a 4" diameter line feeding a 4" diameter spray at the upper part of the absorber. The resulting spray of 4% acid removes the gaseous ammonia from the coke oven gas to form ammonium sulphate which remains in the acid circulating liquid as a dissolved solute. The acid circulating liquor leaves the base of the ammonia absorber through the 10" diameter seal leg and flows via gravity through the 12" diameter return line to the circulating tank in operation.

The removal of the gaseous ammonia from the gas with the formation of ammonium sulphate will result in a reduction in the strength of the circulating acid. This strength reduction is compensated by the introduction of strong sulfuric acid (72%) in a ratio to ensure a 4% H_2SO_4 level in the circulating tank through separate feed lines. The volume of make-up is controlled by the output data from the Autotitrator which measures the acid strength in the acid recirculating lines to the absorber, and modulates the preset feed (3.2 gpm) to the system as required. It is essential to maintain the 4% strength of the acid to avoid slippage of gaseous ammonia past the absorber.

The ammonia sulphate concentration is monitored indirectly by tracking the circulating liquid density with the on-line density meter. The density is controlled by occasional mill water additions.

The constant make-up of acid to the circulating tank will eventually fill it to its pre-determined maximum safe level and the tank level indicator will indicate the need to isolate the on line tank and activate the standby tank. The standby tank will have been charged with the required 4% acid solution. This will allow circulation to the absorber to continue uninterrupted.

The isolated circulating tank containing the ammonium sulphate and the residual 4% acid is neutralized by the addition of an aqueous ammonia solution (27%). This addition is controlled by the pH recorder fitted to the base of each circulating tank.

The neutralized contents of the off-line circulation tank are then transferred through in-line filters to one of the two ammonium sulphate load out tanks using either of the two ammonia solution pumps. Two load-out pumps and truck loading station are provided for removal to sale.

2.0 **GENERAL DESCRIPTION OF PROCESS** (continued)

Three (3) circulating tanks are provided, one of which is always on-line circulating to the absorber, one is primed with 4% acid, ready to go on line when the working circulating tank is full, and one is in the process of being neutralized or transferred to the ammonium sulphate storage tank.

The three (3) ammonium sulphate/acid circulating tanks are provided with an emergency overflow, which is common to all 3 tanks. The overflows discharge by gravity to the existing settling tank from where the overflow liquid can be recovered and returned to either the circulating tanks or the ammonium sulphate storage tanks.

3.0 START-UP PROCEDURE

Preliminary Activities

It is assumed that all new equipment has been cleaned, checked and tested and that the ammonia absorber is by-passed.

1. Check that adequate supplies of all the necessary reagents and services are available, and that all instruments, pumps, and other necessary equipment are functioning correctly.

2. Check that all inlet and outlet valves on the circulating tanks and circulating pumps are closed, including the spray system valves at the absorber.

3. Check that the isolating valves for the strong acid, mill water, and aqueous ammonia are also closed.

Filling the Circulating Tanks

Select the tank to be activated and open the inlet valve on the mill water feed to the tank. Open the isolating valve for the mill water supply and close the isolating valves for the control valve L.C.V. 308 and open the by-pass valve, thus allowing water to flow to the circulating tank.

Activate the steam injection system to the water supply line and monitor the water flow from the flow indicator (F.I. 308) until the required volume of water has been fed to the circulating tank (approx. 2,000 gallons) and stop the supply when this volume has been reached.

Set the control station F.C.V. 308 with the flow at the 10 gpm rate (Line No. A.A. 32-102). The isolating valve on the strong acid supply line can now be opened and the selected strong acid feed pump can be started after the supply to the settling basin has been isolated. Monitor the supply of acid to the circulating tank using the meter at the F.C.V. station (F.C.V. 308) (approx. 71 gallons).

Allow approximately 15 minutes for the tank mixer to thoroughly mix the strong acid and water and distribute the heat of solution. A sample of this liquor should be manually titrated to confirm the concentration.

3.0 **START-UP PROCEDURE** (continued)

<u>**Start the Mixer on the Circulating Tank**</u>

It should be noted that the first fill of liquor to the circulating tanks must be 2,500 gallons to allow for the "dead" portion of the tank (i.e, from the tank base to the suction branch). Subsequently, fills will only need to be 2,000 gallons total. The first fill will therefore be 2,500 gallons of mill water and approximately 89 gallons of sulfuric acid.

A strong warning must be made that the water addition must always be made before the acid addition. Water addition to a strong sulfuric acid solution can lead to a large release of heat energy with possible pressure increases and/or explosion potential.

The circulation to the absorber can now commence. Open the 10" suction line at the circulating tank and prime the selected circulating pump. Open the 6" and 4" line valves in the supply line to the absorber spray system including the 3 isolating valves to the individual sprays. Start the pump and slowly open the delivery line valve and check the individual pressure readings on the absorber sprays and adjust as necessary to ensure even distribution of the spraying liquid.

Monitor the circulating tank level using the tank level indicators (318, 319 or 321, as appropriate) to ensure adequate volume remains after the system has been charged.

Check the acidity level of the circulating liquid using the Autotitration readings.

The system is now ready to be used to remove the gaseous ammonia from the coke oven gas.

The absorber must be purged using either the incoming gas against a closed outlet valve or by the injection of inert gas through the purge connection at the bottom of the absorber. After the purge is complete, gas can be admitted to the absorber and the process is in operation.

The automatic acid make-up system using the Autotitrator must now be activated. The control system F.C.V. 204 is set to the calculated make-up rate of 3.2 gallons/minute, and the titrator readings will cause the control valve to modulate this figure to maintain the acid strength of the

3.0 **START-UP PROCEDURE** (continued)

circulating liquid at 4%, by the increase/decrease in the 72% acid flow to the circulating tank. In order to keep the circulating system stable while removing ammonia from the gas and creating ammonium sulphate, it is essential to control the $(NH_4)_2SO_4$ concentration as a function of time to insure that it does not exceed the designated 39% level by the end of the cycle. The $(NH_4)_2SO_4$ concentration can be monitored and controlled via the solution density. Without any water additions, the $(NH_4)_2SO_4$ concentration would build up too rapidly leading to precipitation problems. The higher density of the liquid would require the addition of a controlled amount of water. However, the addition of the ammonia rich steam vapors from the ammonia still adds a substantial amount of water vapor to the system, which may eliminate the need for water additions.

The water loss from the system due to saturating the superheated incoming coke oven gas must also be considered. The density recording element D.E. 204 will indicate the necessity for water addition. The theoretical Material Balance Table in Section 9.2 should be used as a guide to the density of the circulating liquor and its specific gravity in relation to the time elapsed in the absorbing cycle, and the need to make a water addition.

In the event that water addition is needed on a temporary basis, this can be provided using the by-pass line to LCV 308 for approximately 2 minutes (200 gallons). However, in the event that the material balance reveals a need for water make-up on a continuous basis, the following options are available:

1. Increase the ammonia still head temperature.
2. Inject a controlled amount of steam into the incoming coke oven gas main.
3. Inject water on an hourly basis as described for temporary make-up.
4. Inject water through one of the spray arrestor's wash water nozzles.

The acidity, density and specific gravity of the circulating liquor must be monitored throughout the absorbing cycle until the level indicator (LE 318, 319, 321) shows that the circulating tank has reached its maximum safe level and must be isolated. This will coincide with the density of approximately 39% and a

3.0 START-UP PROCEDURE (continued)

specific gravity of 1.23 at about 20 hours into the absorbing cycle. The aim final $(NH_4)_2SO_4$ concentration of 39% for the circulation stage has been developed as the optimum with respect to product quality and operating constraints. Details are provided in Section 7.1.

The full tank should now be isolated and the return flow from the absorber diverted to the standby circulation tank which has been prepared. The valve on the suction line from the standby tank should be opened and the valve on the full tank closed. The full tank is now ready for neutralization and the meter measuring the aqueous ammonia to the full tank should be set to pass approximately 816 gallons of 27% strength ammonia at the pump rate of 30 gpm. The feed rate is lowered near the end to safely bring the tank to a totally neutral condition in approximately 60 minutes.

The Material Balance Table in Section 9.2 should be used to control this operation in conjunction with the pH recorders AE 318,319, 321. The full tank is now ready for transfer to the ammonium sulphate storage tanks. The selected ammonium solution pump should be opened up to the full tank and the selected filter also opened to the outgoing flow, with the ammonium sulphate storage tanks valved in to receive the neutralized liquor.

When the transfer is completed, the air injection/ agitation system must be activated and the empty circulation tank filled with the 4% acid solution as standby.

This completes one cycle of ammonia removal and sulphate production. The procedures are repeated continuously in this manner.

4.0 PROCESS CONTROL SYSTEMS

Refer to P&I diagram #C7541 in Section 8.0.

The control of the system requires that two major parameters be established and maintained to ensure safe and successful operation.

1. The circulating acid/sulphate liquor must be maintained at an acidity level of 4%. This will ensure that the concentration of ammonia in the gas exiting the absorber will not exceed 5 grains per 100 cubic feet.

4.0 PROCESS CONTROL SYSTEMS (continued)

2. The $(NH_4)_2SO_4$ content of the acid/sulphate circulating liquor must not be allowed to exceed 39% and the specific gravity kept below 1.23. This will allow the $(NH_4)_2SO_4$ level to be below 42% after neutralization. $(NH_4)_2SO_4$ will not precipitate upon cooling to 68°F if the concentration is kept below 43.8%. This level will normally be reached after the circulating tank on-line has been in operation for approximately 20 hours.

These required conditions are established and maintained in the case of the circulating liquor acidity by the action of the Autotitrator AIT 416, which continuously monitors the liquor acidity to the absorber sprays and transmits signals to the flow control valve (F.C.V. 204), which then increases/ decreases the acid make-up flow to the on-line circulating tank as required.

In the case of the acid/sulphate liquor density, this is continuously monitored by the density meter (DE 204), which records and alarms any abnormal increase in density.

Additionally, the density recorder will transmit a signal to shut down the acid/sulphate circulating pumps when the "High High" level of density is reached. These pumps will also be shut down in the event of a "High High" level being reached in the run-off seal leg from the absorber base Level Alarm System (L.A. 204).

The density control system will only alarm or shut down the system when absolute density limits are exceeded. At this point, significant quantities of water must be added to lower the $(NH_4)_2SO_4$ concentration or the circulation tank must be taken off line. It is therefore imperative that the operator routinely monitor the density. The density, as a function of tank volume, can be compared to the standard values contained in the Material Balance Table in Section 9.2. The operator can use the information to make small, timely water additions to keep the system in control. Sample density and specific gravity control SPC charts are included in Sections 9.5 and 9.6 as a guide for this procedure.

The level indicator (L.E. 318, 319, 321, as appropriate) will send a signal to the acid/water control station F.C.V. 308 and L.C.V. 308, which will shut off the supply

4.0 **PROCESS CONTROL SYSTEMS** (continued)

of acid and water make-up to the circulating tank on-line. It will not, however, stop the circulating pumps, which, if allowed to continue, will bring in additional volumes of $(NH_4)_2SO_4$ from the absorber and cause overflow of the tank and/or high $(NH_4)_2SO_4$ levels.

The high alarm signal from LSHH 318, 319, 321 will indicate that a tank switch must be made immediately. Careful attentive operation will avoid this situation by the use of the Material Balance Tables and checking the level indicator (L.I. 318, 319, 321).

Each circulating tank is fitted with a temperature measuring element (T.E. 318, 319, 321) which maintains the accuracy of the ultrasonics in the level indicators by compensating for temperature changes in the liquid.

The level indicators and the liquid density recorder will indicate that the on-line circulating tank is ready to be isolated and the next circulating tank brought into operation.

Neutralization of the full circulating tank taken off-line is affected by the injection of aqueous ammonia into the full tank. This addition is controlled by the Flow Indicator Control 323 located in the feed line from the aqueous ammonia feed pumps to the full circulating tank. The Flow Meter (F.E.323) is set to pass the calculated volume to neutralize the residual acid in the ammonium sulphate/acid liquor full tank. The progress and completion of this process is monitored by the pH analyzer (A.E. 318, 319, 321, as appropriate), which is located in the base of eac[illegible] circulating tank. The analyzer transmits a signal to the Flow Control Valve 323, which modulates the feed of aqueous ammonia to the tank to complete neutralization.

5.0 NORMAL OPERATING PROCEDURE

The normal operating condition will ensure uninterrupted removal of the gaseous ammonia from the coke oven gas with the production of ammonium sulphate in an aqueous neutral solution.

The neutralization of the circulating acid/sulphate liquor and the transfer of circulating tanks is, however, a batch process which requires the changeover in cycles of approximately 20 hours.

The neutralization process requires approximately 60 minutes and need not be carried out immediately, provided that the third of the circulating tanks is primed with the necessary circulating liquor. The transfer of the neutralized ammonium sulphate to the storage tanks for load out takes approximately 80 minutes.

During the circulating stage of a particular tank, it is necessary to check on an hourly basis the circulating liquor acidity to ensure that the 4% acidity is being maintained and that the density of the liquor is in accordance with the tank volume and the time elapsed from the commencement of the tank circulation. The Material Balance Chart in Section 9.2 should be studied for guidance in this respect.

As the on-line circulating tank approaches its maximum capacity, the suction valve feeding the standby circulating pump should be opened and the pump primed. The pump should be started, the delivery valve opened slowly and the delivery valve of the on-line pump closed. The inlet valve to the new on line tank can now be opened and the full tank inlet valve closed.

To complete the changeover, the Hand Switch (HS 1) must be switched to the new tank to activate the new level measuring/control device.

At this stage it is advisable to pump out the neutralized tank and transfer the contents to the ammonium sulphate storage tank to make this circulating tank available for filling with the 4% acid solution ready for the next changeover. This procedure should be carried out as stated in the start-up instructions in this manual, except that the control system L.C.V. 308 will be temporarily isolated to allow the mill water by-pass line

5.0 **NORMAL OPERATING PROCEDURE** (continued)

to this control valve to be used to feed the initial water fill of approximately 2,000 gallons (approximately 20 minutes). The acid feed of approximately 71 gallons (72% H_2SO_4) will be fed into the tank using the by-pass line round F.C.V. 308 (approximately 7 minutes).

The mixer should be activated as soon as the acid begins to enter the tank.

6.0 DAILY TESTS AND DATA COLLECTION

During the normal operating period, the following tests should be carried out:

Manual titration on samples of the circulating liquor to confirm the accuracy or otherwise of the Autotitrator must be made once per shift and results recorded (the equipment for manual titration must always be readily available in case of malfunction of the Autotitrator).

Similar density or specific gravity checks must also be carried out. This can be done by weighing a known volume of solution.

Ammonia concentration in the coke oven gas should be checked, if possible, together with the gas outlet temperature of the primary coolers and exhausters.

The flow rate and NH_3 composition of the ammonia liquor feed to the stills and the residual total ammonia in the still effluent should also be monitored to provide information on the NH_3 loading from the stills to the absorber.

7.0 SPECIFICATION AND QUANTITIES OF MATERIALS AND SERVICES FOR NORMAL OPERATION

Design Basis

Coke Oven Gas Inlet	
Flow Rate (dry)	30 MMSCFD (20,833/scfm)
Inlet Temperature	131°F (55°C)
NH_3 Content	7.44 lbs./min. (250 gr./100 cu. ft.)
NH_3 Still Vapors	
NH_3 Vapor Flow Rate	2.42 lb./min.
H_2O Vapor Flow Rate	13.71 lb./min.
Temperature	approx. 200°F
Coke Oven Gas Outlet	
Flow Rate (dry)	30 MMSCFD (20,833 SCFM)
Outlet Temperature	140°F (60°C)
Saturator	
$(NH_4)_2SO_4$ Production	37.7 lb./min (27.1 ton/day)
H_2SO_4 Consumption	28.0 lb./min (20.2 ton/day)

Service Requirements

H_2SO_4 (72%)	3,911 gallons/tank cycle
Aqueous Ammonia (27%)	816 gallons/tank cycle 979 gal/day
Millwater	20 gpm/(max.) plus tank fill (2,000 gallons)
150 lbs. Steam	
480 volt Electrical Energy	

7.1 $(NH_4)_2SO_4$ Concentration Requirements

Product quality requirements

- Producing a 90010 grade product requires a guaranteed minimum 9% NH_3 product. This is equivalent to a 35% $(NH_4)_2SO_4$ minimum at all times.

- Producing a 90010 grade product will result in an increased value product over the current 80010 grade product.

- The 10% SO_4/PO_4 requirement should always be met (greater than 14% $(NH_4)_2SO_4$).

7.1 **$(NH_4)_2SO_4$ Concentration Requirements** (continued)

Operating Concerns

- $(NH_4)_2SO_4$ solubility limits

140°F (60°C)	46.8%
68°F (20°C)	43.8%

- Want final product (after neutralization) to be $\leq$ 42% $(NH_4)_2SO_4$ to insure no precipitation upon cooling in the loadout tanks. The maximum $(NH_4)_2SO_4$ concentration must be kept below 39% to allow for $(NH_4)_2SO_4$ formation during neutralization.

- Maximizing $(NH_4)_2SO_4$ concentration in the solution allows for greater NH_3 absorption and thus longer cycle times between tank changes.

9.0 MATERIAL BALANCE AND PROCESS TABLES

9.1 Line Drawing of Process Flow Sheet

9.2 Material Balance Calculations for Typical Operation

9.3 Expected Density vs. Tank Volume for Typical Operation

9.4 Expected Specific Gravity vs. Tank Volume for Typical Operation

9.5 Density Control SPC Limits vs. Tank Volume for Typical Operation

9.6 Specific Gravity Control SPC Limits vs. Tank Volume for Typical Operation

9.2 Material Balane Calculations for Typical Operation

Acme Ammonia Sulfate Material Balance Calculations

20	1200	min connected to process	58	min neutralization
min time increments	20.00	hr	0.97	hr

Time	Addition Rate (gpm)		Wt (lbs)				Per Cent				Specific	Volume
(min)	H2O	H2SO4	H2O	H2SO4	NH42SO4	Total	H2O	H2SO4	NH42SO4	Total	Gravity	(gal)
0	NA	NA	16646.7	694.1	0.0	17340.8	96.00	4.00	0.00	100.00	1.008	2065.6
20	3.50	3.20	17473.1	760.0	754.0	18987.1	92.03	4.00	3.97	100.00	1.030	2212.4
40	3.50	3.20	18299.5	825.8	1508.0	20633.4	88.69	4.00	7.31	100.00	1.049	2361.0
60	3.50	3.20	19125.9	891.7	2262.0	22279.7	85.84	4.00	10.15	100.00	1.065	2511.0
80	3.50	3.20	19952.4	957.6	3016.0	23925.9	83.39	4.00	12.61	100.00	1.079	2661.9
100	3.50	3.20	20778.8	1023.4	3770.0	25572.2	81.26	4.00	14.74	100.00	1.091	2813.6
120	3.50	3.20	21605.2	1089.3	4524.0	27218.5	79.38	4.00	16.62	100.00	1.102	2965.8
140	3.50	3.20	22431.6	1155.2	5278.0	28864.8	77.71	4.00	18.29	100.00	1.111	3118.6
160	3.50	3.20	23258.0	1221.1	6032.0	30511.1	76.23	4.00	19.77	100.00	1.120	3271.8
180	3.50	3.20	24084.4	1286.9	6786.0	32157.4	74.90	4.00	21.10	100.00	1.127	3425.3
200	3.50	3.20	24910.9	1352.8	7540.0	33803.7	73.69	4.00	22.31	100.00	1.134	3579.1
220	3.50	3.20	25737.3	1418.7	8294.0	35449.9	72.60	4.00	23.40	100.00	1.140	3733.1
240	3.50	3.20	26563.7	1484.5	9048.0	37096.2	71.61	4.00	24.39	100.00	1.146	3887.3
260	3.50	3.20	27390.1	1550.4	9802.0	38742.5	70.70	4.00	25.30	100.00	1.151	4041.6
280	3.50	3.20	28216.5	1616.3	10556.0	40388.8	69.86	4.00	26.14	100.00	1.155	4196.2
300	3.50	3.20	29042.9	1682.1	11310.0	42035.1	69.09	4.00	26.91	100.00	1.160	4350.8
320	3.50	3.20	29869.4	1748.0	12064.0	43681.4	68.38	4.00	27.62	100.00	1.164	4505.6
340	3.50	3.20	30695.8	1813.9	12818.0	45327.7	67.72	4.00	28.28	100.00	1.168	4660.5
360	3.50	3.20	31522.2	1879.8	13572.0	46973.9	67.11	4.00	28.89	100.00	1.171	4815.4
380	3.50	3.20	32348.6	1945.6	14326.0	48620.2	66.53	4.00	29.47	100.00	1.174	4970.5
400	3.50	3.20	33175.0	2011.5	15080.0	50266.5	66.00	4.00	30.00	100.00	1.177	5125.6
420	3.50	3.20	34001.4	2077.4	15834.0	51912.8	65.50	4.00	30.50	100.00	1.180	5280.7
440	3.50	3.20	34827.9	2143.2	16588.0	53559.1	65.03	4.00	30.97	100.00	1.183	5436.0
460	3.50	3.20	35654.3	2209.1	17342.0	55205.4	64.58	4.00	31.41	100.00	1.185	5591.3
480	3.50	3.20	36480.7	2275.0	18096.0	56851.7	64.17	4.00	31.83	100.00	1.188	5746.6
500	3.50	3.20	37307.1	2340.8	18850.0	58497.9	63.78	4.00	32.22	100.00	1.190	5901.9
520	3.50	3.20	38133.5	2406.7	19604.0	60144.2	63.40	4.00	32.59	100.00	1.192	6057.4
540	3.50	3.20	38959.9	2472.6	20358.0	61790.5	63.05	4.00	32.95	100.00	1.194	6212.8
560	3.50	3.20	39786.3	2538.4	21112.0	63436.8	62.72	4.00	33.28	100.00	1.196	6368.3
580	3.50	3.20	40612.8	2604.3	21866.0	65083.1	62.40	4.00	33.60	100.00	1.198	6523.8
600	3.50	3.20	41439.2	2670.2	22620.0	66729.4	62.10	4.00	33.90	100.00	1.199	6679.3

620	3.50	3.20	42265.6	2736.1	23374.0	68375.7	61.81	4.00	34.18	100.00	1.201	6834.9
640	3.50	3.20	43092.0	2801.9	24128.0	70021.9	61.54	4.00	34.46	100.00	1.202	6990.5
660	3.50	3.20	43918.4	2867.8	24882.0	71668.2	61.28	4.00	34.72	100.00	1.204	7146.1
680	3.50	3.20	44744.8	2933.7	25636.0	73314.5	61.03	4.00	34.97	100.00	1.205	7301.7
700	3.50	3.20	45571.3	2999.5	26390.0	74960.8	60.79	4.00	35.21	100.00	1.207	7457.3
720	3.50	3.20	46397.7	3065.4	27144.0	76607.1	60.57	4.00	35.43	100.00	1.208	7613.0
740	3.50	3.20	47224.1	3131.3	27898.0	78253.4	60.35	4.00	35.65	100.00	1.209	7768.7
760	3.50	3.20	48050.5	3197.1	28652.0	79899.7	60.14	4.00	35.86	100.00	1.210	7924.4
780	3.50	3.20	48876.9	3263.0	29406.0	81545.9	59.94	4.00	36.06	100.00	1.212	8080.1
800	3.50	3.20	49703.3	3328.9	30160.0	83192.2	59.75	4.00	36.25	100.00	1.213	8235.8
820	3.50	3.20	50529.8	3394.8	30914.0	84838.5	59.56	4.00	36.44	100.00	1.214	8391.5
840	3.50	3.20	51356.2	3460.6	31668.0	86484.8	59.38	4.00	36.62	100.00	1.215	8547.3
860	3.50	3.20	52182.6	3526.5	32422.0	88131.1	59.21	4.00	36.79	100.00	1.216	8703.0
880	3.50	3.20	53009.0	3592.4	33176.0	89777.4	59.04	4.00	36.95	100.00	1.217	8858.8
900	3.50	3.20	53835.4	3658.2	33930.0	91423.7	58.89	4.00	37.11	100.00	1.217	9014.6
920	3.50	3.20	54661.8	3724.1	34684.0	93069.9	58.73	4.00	37.27	100.00	1.218	9170.4
940	3.50	3.20	55488.3	3790.0	35438.0	94716.2	58.58	4.00	37.41	100.00	1.219	9326.2
960	3.50	3.20	56314.7	3855.8	36192.0	96362.5	58.44	4.00	37.56	100.00	1.220	9482.0
980	3.50	3.20	57141.1	3921.7	36946.0	98008.8	58.30	4.00	37.70	100.00	1.221	9637.8
1000	3.50	3.20	57967.5	3987.6	37700.0	99655.1	58.17	4.00	37.83	100.00	1.222	9793.6
1020	3.50	3.20	58793.9	4053.5	38454.0	101301.4	58.04	4.00	37.96	100.00	1.222	9949.4
1040	3.50	3.20	59620.3	4119.3	39208.0	102947.7	57.91	4.00	38.09	100.00	1.223	10105.3
1060	3.50	3.20	60446.7	4185.2	39962.0	104593.9	57.79	4.00	38.21	100.00	1.224	10261.1
1080	3.50	3.20	61273.2	4251.1	40716.0	106240.2	57.67	4.00	38.32	100.00	1.224	10417.0
1100	3.50	3.20	62099.6	4316.9	41470.0	107886.5	57.56	4.00	38.44	100.00	1.225	10572.8
1120	3.50	3.20	62926.0	4382.8	42224.0	109532.8	57.45	4.00	38.55	100.00	1.226	10728.7
1140	3.50	3.20	63752.4	4448.7	42978.0	111179.1	57.34	4.00	38.66	100.00	1.226	10884.5
1160	3.50	3.20	64578.8	4514.5	43732.0	112825.4	57.24	4.00	38.76	100.00	1.227	11040.4
1180	3.50	3.20	65405.2	4580.4	44486.0	114471.7	57.14	4.00	38.86	100.00	1.227	11196.3
1200	3.50	3.20	66231.7	4646.3	45240.0	116117.9	57.04	4.00	38.96	100.00	1.228	11352.2

Aqua Ammonia Addition

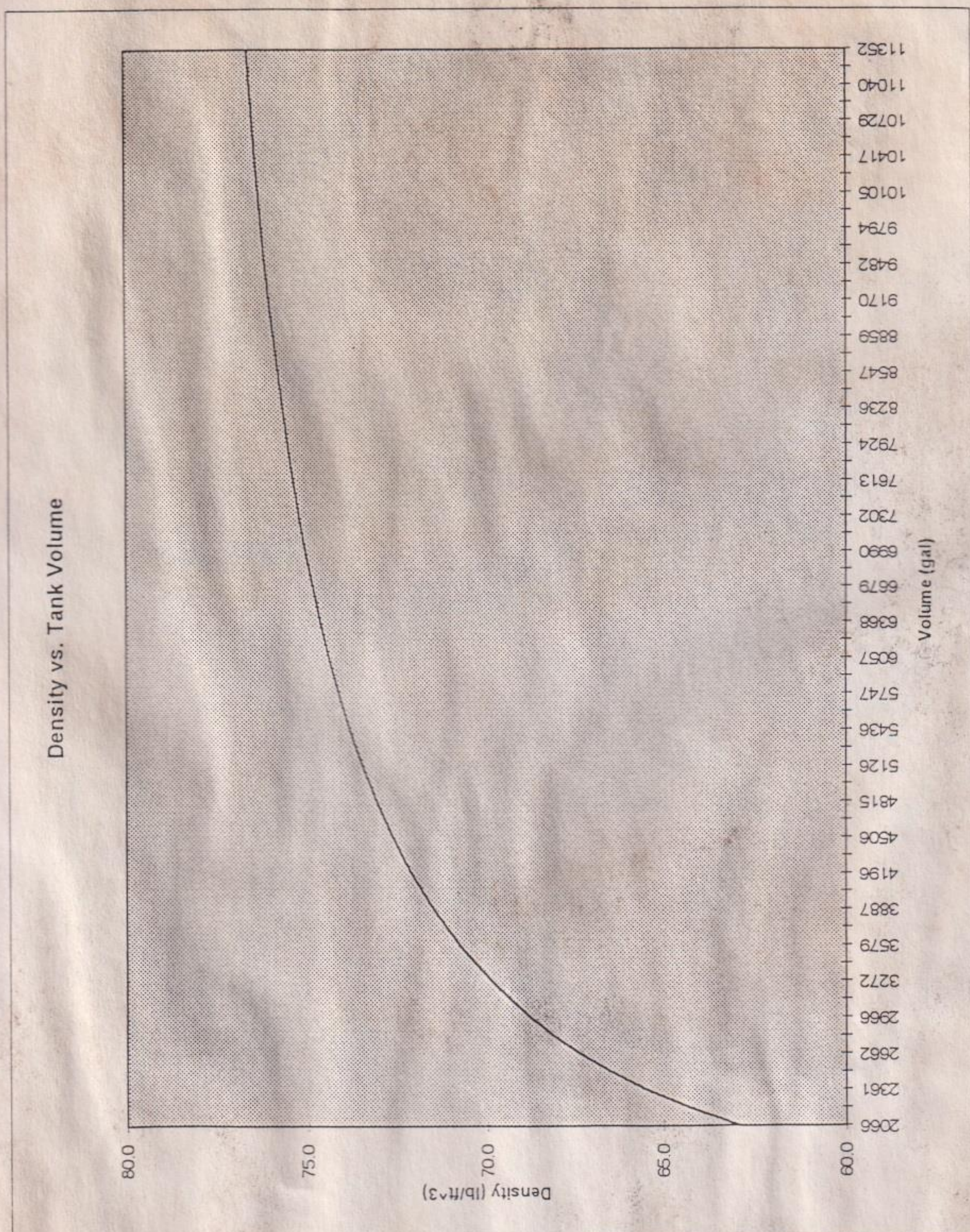
1 min time increments

	Rate	Total	Wt (lbs)				Per Cent				Specific	Volume	
Time	(gpm)	(gal)	H2O	H2SO4	NH42SO4	Total	H2O	H2SO4	NH42SO4	Total	Gravity	(gal)	pH
1200	NA	0	66232	4646	45240	116118	57.04	4.00	38.96	100.00	1.228	11352.2	0.30
1201	30	30	66392	4475	45470	116338	57.07	3.85	39.08	100.00	1.228	11376.0	0.32

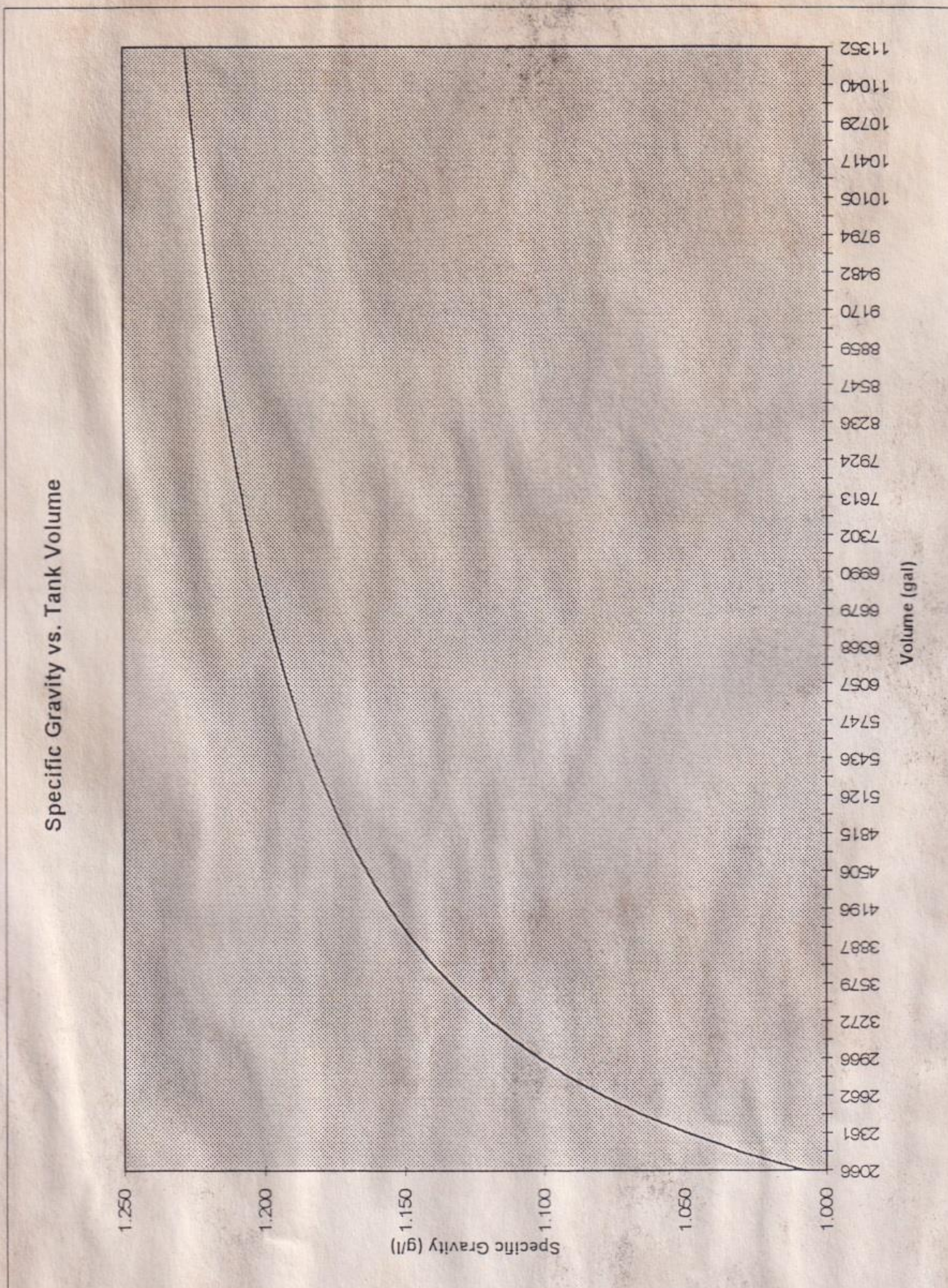
1202	30	60	66553	4305	45700	116558	57.10	3.69	39.21	100.00	1.227	11399.8	0.33
1203	30	90	66713	4134	45931	116778	57.13	3.54	39.33	100.00	1.227	11423.6	0.35
1204	30	120	66874	3963	46161	116998	57.16	3.39	39.45	100.00	1.227	11447.4	0.37
1205	30	150	67034	3792	46391	117217	57.19	3.24	39.58	100.00	1.227	11471.2	0.39
1206	30	180	67195	3621	46621	117437	57.22	3.08	39.70	100.00	1.226	11495.0	0.41
1207	30	210	67355	3451	46851	117657	57.25	2.93	39.82	100.00	1.226	11518.8	0.44
1208	30	240	67516	3280	47081	117877	57.28	2.78	39.94	100.00	1.226	11542.6	0.46
1209	30	270	67676	3109	47312	118097	57.31	2.63	40.06	100.00	1.226	11566.4	0.48
1210	30	300	67837	2938	47542	118317	57.33	2.48	40.18	100.00	1.225	11590.2	0.51
1211	30	330	67998	2767	47772	118537	57.36	2.33	40.30	100.00	1.225	11614.0	0.53
1212	30	360	68158	2597	48002	118757	57.39	2.19	40.42	100.00	1.225	11637.8	0.56
1213	30	390	68319	2426	48232	118977	57.42	2.04	40.54	100.00	1.225	11661.6	0.59
1214	30	420	68479	2255	48463	119197	57.45	1.89	40.66	100.00	1.225	11685.4	0.63
1215	30	450	68640	2084	48693	119417	57.48	1.75	40.78	100.00	1.224	11709.2	0.66
1216	30	480	68800	1913	48923	119637	57.51	1.60	40.89	100.00	1.224	11733.0	0.70
1217	30	510	68961	1743	49153	119856	57.54	1.45	41.01	100.00	1.224	11756.8	0.74
1218	30	540	69121	1572	49383	120076	57.56	1.31	41.13	100.00	1.224	11780.6	0.79
1219	30	570	69282	1401	49614	120296	57.59	1.16	41.24	100.00	1.223	11804.4	0.84
1220	30	600	69442	1230	49844	120516	57.62	1.02	41.36	100.00	1.223	11828.2	0.89
1221	30	630	69603	1059	50074	120736	57.65	0.88	41.47	100.00	1.223	11852.0	0.96
1222	25	655	69737	917	50266	120919	57.67	0.76	41.57	100.00	1.223	11871.9	1.02
1223	25	680	69870	775	50458	121103	57.70	0.64	41.67	100.00	1.223	11891.7	1.10
1224	20	700	69977	661	50611	121249	57.71	0.54	41.74	100.00	1.222	11907.6	1.17
1225	20	720	70085	547	50764	121396	57.73	0.45	41.82	100.00	1.222	11923.5	1.25
1226	15	735	70165	461	50880	121506	57.75	0.38	41.87	100.00	1.222	11935.4	1.32
1227	15	750	70245	376	50995	121616	57.76	0.31	41.93	100.00	1.222	11947.3	1.41
1228	10	760	70299	319	51071	121689	57.77	0.26	41.97	100.00	1.222	11955.2	1.49
1229	10	770	70352	262	51148	121762	57.78	0.22	42.01	100.00	1.222	11963.2	1.57
1230	5	775	70379	234	51186	121799	57.78	0.19	42.03	100.00	1.222	11967.1	1.62
1231	5	780	70406	205	51225	121836	57.79	0.17	42.04	100.00	1.222	11971.1	1.68
1232	5	785	70432	177	51263	121872	57.79	0.15	42.06	100.00	1.222	11975.1	1.74
1233	5	790	70459	148	51302	121909	57.80	0.12	42.08	100.00	1.222	11979.0	1.82
1234	2	792	70470	137	51317	121924	57.80	0.11	42.09	100.00	1.222	11980.6	1.85
1235	2	794	70481	126	51332	121938	57.80	0.10	42.10	100.00	1.222	11982.2	1.89
1236	2	796	70491	114	51348	121953	57.80	0.09	42.10	100.00	1.222	11983.8	1.93
1237	2	798	70502	103	51363	121968	57.80	0.08	42.11	100.00	1.222	11985.4	1.98
1238	1	799	70507	97	51371	121975	57.80	0.08	42.12	100.00	1.222	11986.2	2.00
1239	1	800	70513	91	51378	121982	57.81	0.07	42.12	100.00	1.222	11987.0	2.03

1240	1	801	70518	86	51386	121990	57.81	0.07	42.12	100.00	1.222	11987.8	2.06
1241	1	802	70523	80	51394	121997	57.81	0.07	42.13	100.00	1.222	11988.6	2.09
1242	1	803	70529	74	51401	122004	57.81	0.06	42.13	100.00	1.222	11989.4	2.12
1243	1	804	70534	69	51409	122012	57.81	0.06	42.13	100.00	1.222	11990.2	2.15
1244	1	805	70539	63	51417	122019	57.81	0.05	42.14	100.00	1.222	11991.0	2.19
1245	1	806	70545	57	51424	122026	57.81	0.05	42.14	100.00	1.222	11991.7	2.23
1246	1	807	70550	52	51432	122034	57.81	0.04	42.15	100.00	1.222	11992.5	2.28
1247	1	808	70555	46	51440	122041	57.81	0.04	42.15	100.00	1.222	11993.3	2.33
1248	1	809	70561	40	51447	122048	57.81	0.03	42.15	100.00	1.222	11994.1	2.39
1249	1	810	70566	34	51455	122056	57.81	0.03	42.16	100.00	1.222	11994.9	2.45
1250	1	811	70571	29	51463	122063	57.82	0.02	42.16	100.00	1.222	11995.7	2.53
1251	1	812	70577	23	51470	122070	57.82	0.02	42.16	100.00	1.222	11996.5	2.63
1252	1	813	70582	17	51478	122078	57.82	0.01	42.17	100.00	1.222	11997.3	2.75
1253	1	814	70588	12	51486	122085	57.82	0.01	42.17	100.00	1.222	11998.1	2.92
1254	0.5	814.5	70590	9	51490	122089	57.82	0.01	42.17	100.00	1.222	11998.5	3.04
1255	0.5	815	70593	6	51493	122092	57.82	0.00	42.18	100.00	1.222	11998.9	3.21
1256	0.5	815.5	70596	3	51497	122096	57.82	0.00	42.18	100.00	1.222	11999.3	3.49
1257	0.5	816	70598	0	51501	122100	57.82	0.00	42.18	100.00	1.222	11999.7	4.53
1258	0.5	816.5	70601	-3	51505	122103	57.82	0.00	42.18	100.00	1.222	12000.1	7.00

9.3 Expected Density vs. Tank Volume for Typical Operation



9.4 Expected Specific Gravity vs. Tank Volume for Typical Operation



9.5 Density Control SPC Limits vs. Tank Volume for Typical Operation

Density Control Limits

Time (min)	Volume (gal)	Density (lb/ft^3) Lower Limit	Aim	Upper Limit
0	2065.6	59.7	62.9	66.0
20	2212.4	61.1	64.3	67.5
40	2361.0	62.2	65.5	68.7
60	2511.0	63.1	66.5	69.1
80	2661.9	64.0	67.3	70.0
100	2813.6	64.7	68.1	70.8
120	2965.8	66.0	68.7	71.5
140	3118.6	66.6	69.3	72.1
160	3271.8	67.1	69.9	72.7
180	3425.3	67.5	70.3	72.4
200	3579.1	67.9	70.8	72.9
220	3733.1	68.3	71.1	73.3
240	3887.3	68.6	71.5	72.9
260	4041.6	68.9	71.8	73.2
280	4196.2	69.2	72.1	73.5
300	4350.8	69.5	72.4	73.8
320	4505.6	69.7	72.6	74.1
340	4660.5	69.9	72.9	74.3
360	4815.4	70.2	73.1	74.5
380	4970.5	70.3	73.3	74.7
400	5125.6	70.5	73.5	74.9
420	5280.7	70.7	73.6	75.1
440	5436.0	70.9	73.8	75.3
460	5591.3	71.0	74.0	74.7
480	5746.6	71.1	74.1	74.9
500	5901.9	71.3	74.2	75.0
520	6057.4	71.4	74.4	75.1
540	6212.8	71.5	74.5	75.2
560	6368.3	72.4	74.6	75.4
580	6523.8	72.5	74.7	75.5
600	6679.3	72.6	74.8	75.6
620	6834.9	72.7	74.9	75.7
640	6990.5	72.8	75.0	75.8
660	7146.1	72.9	75.1	75.9
680	7301.7	73.0	75.2	76.0
700	7457.3	73.0	75.3	76.1
720	7613.0	73.1	75.4	76.1
740	7768.7	73.2	75.5	76.2
760	7924.4	73.3	75.5	76.3
780	8080.1	73.3	75.6	76.4
800	8235.8	73.4	75.7	76.4
820	8391.5	73.5	75.7	76.5
840	8547.3	73.5	75.8	76.6
860	8703.0	74.0	75.9	75.9
880	8858.8	74.0	75.9	75.9
900	9014.6	74.1	76.0	76.0
920	9170.4	74.1	76.0	76.0
940	9326.2	74.2	76.1	76.1
960	9482.0	74.2	76.1	76.1
980	9637.8	74.3	76.2	76.2
1000	9793.6	74.3	76.2	76.2
1020	9949.4	74.4	76.3	76.3
1040	10105.3	74.4	76.3	76.3
1060	10261.1	74.4	76.4	76.4
1080	10417.0	74.5	76.4	76.4
1100	10572.8	74.5	76.4	76.4
1120	10728.7	74.6	76.5	76.5
1140	10884.5	74.6	76.5	76.5
1160	11040.4	74.6	76.6	76.6
1180	11196.3	74.7	76.6	76.6
1200	11352.2	74.7	76.6	76.6

9.6 Specific Gravity Control SPC Limits vs. Tank Volume for Typical Operation

Specific Gravity Control Limits

Time (min)	Volume (gal)	Specific Gravity: Lower Limit	Aim	Upper Limit
0	2065.6	0.96	1.01	1.06
20	2212.4	0.98	1.03	1.08
40	2361.0	1.00	1.05	1.10
60	2511.0	1.01	1.07	1.11
80	2661.9	1.03	1.08	1.12
100	2813.6	1.04	1.09	1.13
120	2965.8	1.06	1.10	1.15
140	3118.6	1.07	1.11	1.16
160	3271.8	1.07	1.12	1.16
180	3425.3	1.08	1.13	1.16
200	3579.1	1.09	1.13	1.17
220	3733.1	1.09	1.14	1.17
240	3887.3	1.10	1.15	1.17
260	4041.6	1.10	1.15	1.17
280	4196.2	1.11	1.16	1.18
300	4350.8	1.11	1.16	1.18
320	4505.6	1.12	1.16	1.19
340	4660.5	1.12	1.17	1.19
360	4815.4	1.12	1.17	1.19
380	4970.5	1.13	1.17	1.20
400	5125.6	1.13	1.18	1.20
420	5280.7	1.13	1.18	1.20
440	5436.0	1.14	1.18	1.21
460	5591.3	1.14	1.19	1.20
480	5746.6	1.14	1.19	1.20
500	5901.9	1.14	1.19	1.20
520	6057.4	1.14	1.19	1.20
540	6212.8	1.15	1.19	1.21
560	6368.3	1.16	1.20	1.21
580	6523.8	1.16	1.20	1.21
600	6679.3	1.16	1.20	1.21
620	6834.9	1.16	1.20	1.21
640	6990.5	1.17	1.20	1.21
660	7146.1	1.17	1.20	1.22
680	7301.7	1.17	1.21	1.22
700	7457.3	1.17	1.21	1.22
720	7613.0	1.17	1.21	1.22
740	7768.7	1.17	1.21	1.22
760	7924.4	1.17	1.21	1.22
780	8080.1	1.18	1.21	1.22
800	8235.8	1.18	1.21	1.22
820	8391.5	1.18	1.21	1.23
840	8547.3	1.18	1.21	1.23
860	8703.0	1.19	1.22	1.22
880	8858.8	1.19	1.22	1.22
900	9014.6	1.19	1.22	1.22
920	9170.4	1.19	1.22	1.22
940	9326.2	1.19	1.22	1.22
960	9482.0	1.19	1.22	1.22
980	9637.8	1.19	1.22	1.22
1000	9793.6	1.19	1.22	1.22
1020	9949.4	1.19	1.22	1.22
1040	10105.3	1.19	1.22	1.22
1060	10261.1	1.19	1.22	1.22
1080	10417.0	1.19	1.22	1.22
1100	10572.8	1.19	1.22	1.22
1120	10728.7	1.19	1.23	1.23
1140	10884.5	1.20	1.23	1.23
1160	11040.4	1.20	1.23	1.23
1180	11196.3	1.20	1.23	1.23
1200	11352.2	1.20	1.23	1.23

9.1 PROCESS FLOW LINES