SYNTHETIC FIBERS

AP-42 Section 5.19
Reference Number
44

EMISSION, PROCESS AND CONTROL TECHNOLOGY STUDY OF THE ABS/SAN, ACRYLIC FIBER, AND NBR INDUSTRIES

Pullman Kellogg
Division of Pullman Incorporated

20 April 1979

EMISSION, PROCESS AND CONTROL TECHNOLOGY STUDY OF THE ABS/SAN, ACRYLIC FIBER, AND NBR INDUSTRIES

by

C. N. Click

and

D. O. Moore

PULLMAN KELLOGG
a Division of Pullman Incorporated
16200 Park Row, Industrial Park Ten
Houston, Texas 77084

Contract No. 68-02-2619, Task No. 6

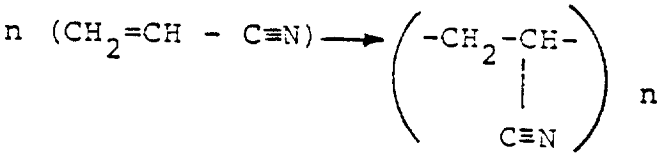
Emission Standards and Engineering Division
Office of Air Quality, Planning, and Standards
U. S. Environmental Protection Agency
Research Triangle Park, N. C. 27711

PART II
ACRYLIC FIBERS

SECTION 1
INDUSTRY DESCRIPTION

1.1 GENERAL INFORMATION

The acrylic fiber industry develops the general categories of fibers based on polymerized acrylonitrile. The polymer is formed by the reaction shown in the following equation:



$$n\ (CH_2{=}CH - C{\equiv}N) \longrightarrow \left(\begin{array}{c}-CH_2-CH-\\ \ \ \ \ |\\ \ \ \ \ C{\equiv}N\end{array}\right)_n$$

Generally, acrylic fibers contain from 85 to 91% acrylonitrile, 7-8% neutral acrylate monomers, and 2 to 5% other monomers and additives. The neutral monomers used are methyl acrylate ($CH_2{=}CH\ COOCH_3$), methyl methacrylate ($CH_2 = C.CH_3\ COOCH_3$, and vinyl acetate ($CH_3 - COO{-}CH = CH_2$). The rest of the polymer is composed of dyeing assistants, colored pigments, titanium dioxide delusterant, optical brighteners, heat stabilizers, fire retardants, and light stabilizers. The polymers formed generally have an average molecular weight of 100,000 to 150,000 (11,p.71; 16,pp.D,E; 14,pp.48-49).

Fibers composed of less than 85% but more than 35% acrylonitrile are called modacrylics. Comonomers used are vinylidene chloride and vinyl chloride. Other monomers such as vinyl halogens or acrylates may be used in the polymer when fire retardation or other specific property modification is desired. Also, as with acrylic fibers, the modacrylic fibers can contain small amounts of dye receptors, delusterants, or other additives (11,pp.70-71; 15,pp.26-27; 16,p.E).

1.2 PRODUCT END USES

Acrylic fiber homopolymer is difficult to dye, but it does have some commercial application because of excellent chemical and weathering resistance (15,p.28).

Acrylic fibers (copolymer, terpolymer, tetrapolymer) are used extensively in carpets, circular knit apparel, pile and fleece fabrics, sweaters, half-hose, blankets, draperies, and upholstery.

Modacrylic fibers (copolymer, terpolymer, tetrapolymer) are normally straighter fibers, and they are used in deep pile fabrics where duplication of the feel and appearance of natural fur is desired. They are also used in carpets, blankets, rugs, and synthetic wigs (16,p.I; 19,p.0).

1.3 CAPACITY

The production capacity of acrylic fiber in the United States for 1978 is indicated in Table 1-1.

Table 1-1 SUMMARY OF ACRYLIC FIBER PRODUCTION CAPACITY IN THE UNITED STATES (19,pp.M-N)

1978 Capacity : MMPPY

Company	Location	Acrylic	Modacrylic	Total
American Cyanamid	Milton, Florida	126 Creslan	-	126
Dow Badische	Williamsburg, VA	78 Zefran	-	78
E.I. DuPont De Nemours	Camden, SC	170 Orlon	-	170
	Waynesboro, VA	135 Orlon	-	135
Monsanto	Decatur, AL	295 Acrilan	25 Elura, SEF	320
Tennessee Eastman	Kingsport, TN	-	36 Verel	36
		804	61	865

1.4 LOCATION OF EXISTING PLANTS

Acrylic fiber is manufactured principally in the Southeast section of the country. The locations and names of the principal manufactures are indicated in Figure 1-1.

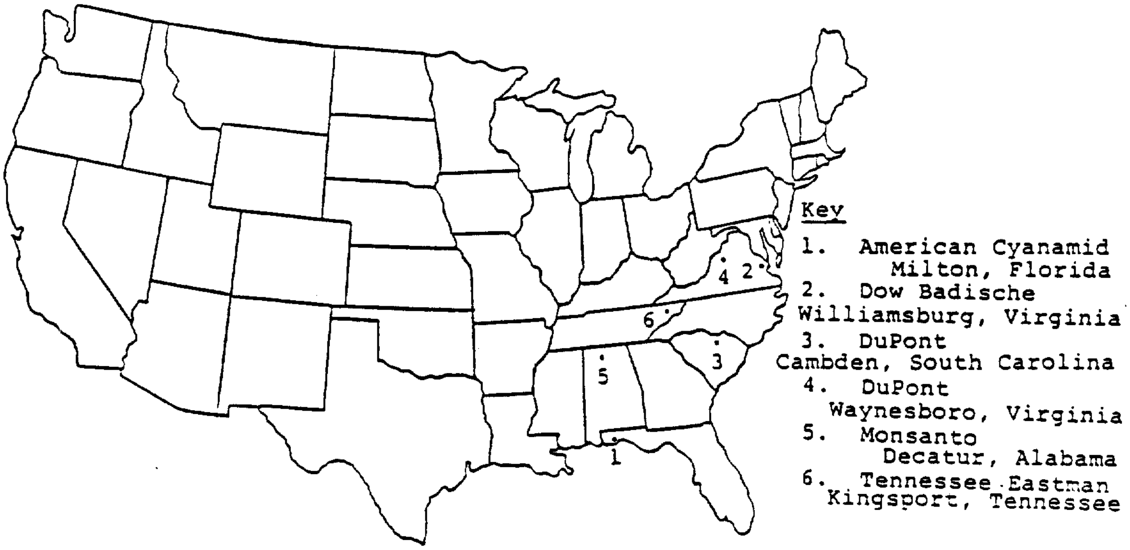


Figure 1-1. - Location of Acrylic Fiber Manufacturing Plants (6, p.2-2

1.5 GROWTH

The following table shows the production rate of acrylic fibers and the average annual growth rate for various years.

Year	Production (Excluding Waste) : MMPPY	Avg Annual Growth : %
1963	209.7	7.9
1975	524.6	18.4
1976	621.0	14.1
1977	708.8	

An annual growth rate of 4.5 to 5.5% per year has been projected for the period 1977 - 1982. If this growth is realized, the 1982 production (excluding waste) will be about 885 to 925 MM PPY. If waste is included, the 1982 production is expected to be about 910 to 955 MM PPY (19.pp.N-O; 21,pp.A,B; 18,p.D).

SECTION II
PROCESS DESCRIPTION

2.1 GENERAL

Polyacrylonitrile resins used to make acrylic and modacrylic fibers are produced by suspension or solution polymerization. Either batch or continuous reaction modes may be employed, and either wet or dry spinning may be used to form the fibers. A variety of spinning solvents are used by industry. Table 2-1 indicates the various methods used domestically to produce acrylic and modacrylic fibers.

The properties of fibers are largely dependent on several factors including:

the inherent chemical structure of the polyacrylonitrile

the kind and amount of modifier used

the spinning method

the degree of stretching (15,p.27)

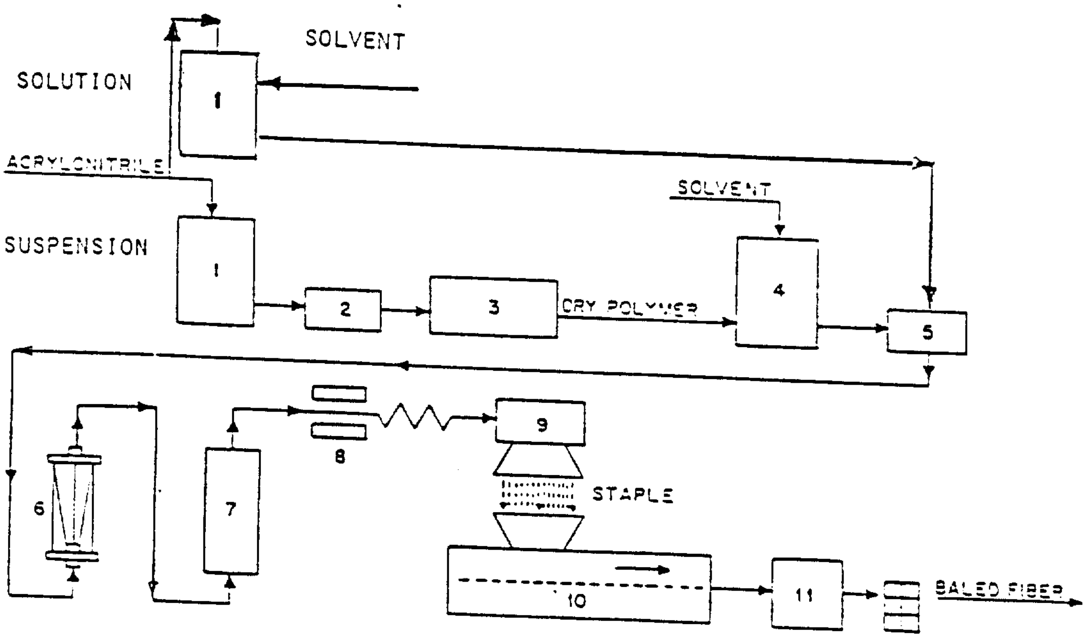
A block diagram, that indicates the acrylic fiber production process, has been developed to indicate the process functions and sequence. The diagram is presented in Figure 2-1.

TABLE 2-1. - ACRYLIC AND MODACRYLIC FIBER PRODUCTION ROUTES

Acrylic Fibers	Registered Trade Name	Typical Chemical Composition of Fiber	Polymerization Medium	Type of Polymerization Operation	Type of Spinning Process	Spinning Solvent
American Cyanamid Company	Creslan	89-90% Acrylonitrile 8% Methyl Methacrylate 2-5% Other	Suspension	Continuous	Wet	Aqueous NaSCN
Dow Badische Company	Zefran	87-90% Acrylonitrile 8% Methyl Acrylate 2-5% Other	Solution	Continuous	Wet	Aqueous $ZnCl_2$
E.I. du Pont De Nemours & Co., Inc.	Orlon	88-91% Acrylonitrile 7% Methyl Acrylate 2-5% Other	Suspension	Continuous	Dry	DMF
Monsanto Company	Acrilan	88-91% Acrylonitrile 8-10% Vinyl Acetate 2-4% Other	Suspension	Batch	Wet	DMAc
Modacrylic Fibers						
E.I. du Pont de Nemours & Company, Inc.	Orlon FLR	66-70% Acrylonitrile 30% Vinyl Chloride 0-4% Other	Suspension	Continuous	Dry	DMF
Eastman Chemical Products, Inc.	Verel	37% Acrylonitrile 40% Vinylidene Chloride 20% Isopropylacrylamide 3% Methyl Acrylate	Solution	Batch	Dry	Acetone
Monsanto Company[1]	Elura	76-78% Acrylonitrile 20% Vinyl Acetate 2-4% Other	Suspension	Batch	Wet	DMAc
	SEF	79-81% Acrylonitrile 8% Vinylidene Chloride 9% Vinyl Bromide 2-4% Other	Suspension	Batch	Wet	DMAc

---

[1] In addition to Elura^R and SEF^R, Monsanto also has two other modacrylic fibers, known as type 65 and type 67 (16,p.F). SOURCE: CEH estimates based on communication with industry.



(1)Polymerization,(2)filtration,(3)drying,(4)dissolving,(5)filtration,
(6)spinning,(7)fiber processing,(8)crimping,(9)cutting,(10)drying,
(11)fiber baling.

Figure 2-1. - Acrylic Fiber Production (15,p.28).

2.2 POLYMER MANUFACTURE

2.2.1 Suspension Polymerization

The suspension polymerization process is accomplished by suspending small drops of acrylonitrile and comonomers in water using violent agitation and a stabilizer which prevents coalescence of the monomer drops. Polymerization occurs in the presence of a catalyst which is soluble in the monomer. Typically, the reaction is carried out to about 65 to 85% completion (11,p.71). Insoluble beads of polymer are formed which are subsequently filtered, washed, refiltered, dried, and milled. Monomers are recovered from the filtration and washing steps and recycled to the polymerization reactors (6,p.2-16).

2.2.2 Solution Polymerization

In this process, acrylonitrile and comonomers are dissolved in either an organic solvent such as dimethylformamide (DMF), dimethylacetamide (DMAC) or acetone, or in a concentrated aqueous solution of zinc chloride, sodium thiocyanate, or nitric acid. Addition of an initiator, such as azobisisobutyonitrile, causes the polymerization reaction to proceed. The polyacrylonitrile (PAN) formed is soluble in the solvent. Since the resulting polymer solution can be used directly in the spinning process to produce fiber, the solution polymerization process appears to offer the advantage of avoiding the filtration, washing, drying, grinding and redissolving steps (16,p.D; 6.p.2-16).

2.3 FIBER SPINNING

The following discussion of the two types of spinning employed by industry uses the schematic developed for both and shown in Figure 2-2 (6,pp.,2-16-18).

2.3.1 Wet Spinning

If solution polymerization was employed to produce the PAN, the solution (spinning dope) is simply filtered, deaerated under vacuum, and pumped to the spinneret. However, if suspension polymerization was used, the dry polymer must be dissolved in the spinning solvent before being filtered, deaerated, and pumped to the spinneret.

A 10 to 25% polymer solution is used in wet spinning. It is advantageous to work with as high a concentration of polymer as possible; however, this leads to increased viscosity which must be overcome by elevating the temperature. The spinneret typically has 1,000 to 30,000 holes which are 2.5 to 4 mils in diameter. The solution is extruded into a spinning bath at 160 to 185°C at 5 to 22 yards/minute. The spinning bath contains solvent diluted with water such t at it causes the fibers to coagulate at the proper rate. The main feature of wet spinning is the mass transfer of solvent from the polymer to the coagulating bath. Wet spinning has an advantage in that the remaining process steps can be continuous; there is no need to stop and collect the tow as in the dry spinning process (10,pp.518-519;16,p.G).

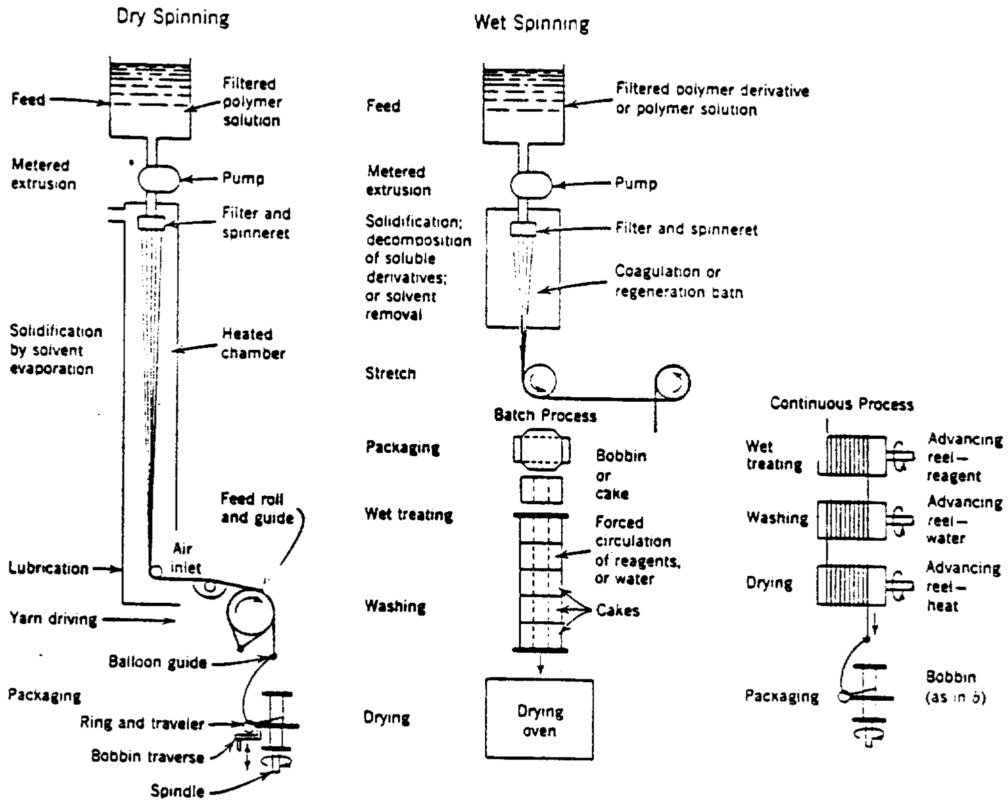


Figure 2-2.-Fiber Spinning (10p.516).

2.3.2 Dry Spinning

A 20 to 25% preheated, filtered solution of polymer is extruded through a spinneret with 200 to 600 holes into a column of hot circulating air which is 50 to 110°C above the boiling point of the solvent. Acetone and DMF are the preferred solvents in commercial dry spinning operations. The solvent evaporates causing the filaments to solidify. They are collected as tow at rates of 100 to 325 yards per minute. Vaporized solvent is condensed in a solvent recovery section and recycled to the dissolving step (10,pp. 517-518).

2.4 Fiber Treating

After either wet or dry spinning, the fibers contain about 10% (wt) residual solvent which must be removed and recovered for economical operation. The fiber is first passed through a heated extraction-drawing bath to recover solvent and to heat the fiber such that it can be drawn. Then the fiber tow is stretched to orient the polyacrylonitrile chains along the fiber axis for improved fiber properties. Stretching is accomplished using rollers rotating at different speeds to elongate each filament from four to seven times its original length. The streching process is normally done using air heated to 80 to 110°C. Hot water or steam at 70 to 110°C may also be used. Figure 2-3 illustrates a typical drawing process. After drawing, the fibers are usually crimped to provide texture which is desirable in some end uses. The fibers are thermally stabilized next, by passing them through a setting dryer which serves to dry them and set their crystalline structure at a higher temperature than they will be exposed to during use. The dried fibers are coated with a small amount of an oil mixture which acts as an antistatic agent and lubricant. Finally the fibers are cut into staple, whose lengths range from 1 1/8 to 6 inches, and baled, left uncut and sold as tow, or wound on bobbins and sold as continuous filament yarn (15,p.28).

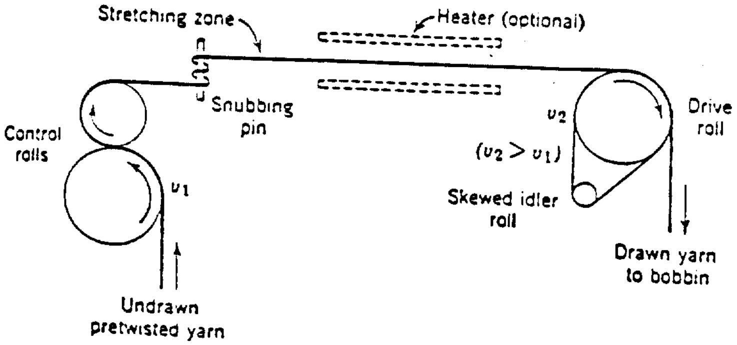


Figure 2-3. - Fiber Drawing (10,p.517).

2.5 Acrylic Fibers - Emissions From Industry

Emissions of AN and VOC from industry are summarized in Table 2-2 below:

TABLE 2-2.-ACRYLIC FIBERS - EMISSIONS FROM INDUSTRY

	Total Emissions From Industry	Total Emissions, TPY
Capacity, MM PPY	865	
AN		
lb/1000	12.08	
PPY	10,445,850	5,223
NON-AN VOC		
lb/1000	20.58	
PPY	17,804,080	8,902
TOTAL VOC		
lb/1000	32.66	
PPY	28,249,930	14,125

SECTION 3

MODEL PLANT DESCRIPTIONS AND FLOWSHEETS

3.1 GENERAL

The model plants chosen to be representative of the acrylic fiber industry are described in this section. These plants include all control technologies considered for this industry. Following the model plant descriptions are descriptions of various control options. These control options use none, some, or all of the control technologies in the model plant. The emissions reduction and costs of each control option are discussed after the control options. For this industry, a model plant capacity of 100 MM PPY was chosen. The polymer was assumed to consist of 100% polyacrylonitrile. A reactor conversion of 87% was used. (95% for the high conversion case). The two different processes considered were suspension polymerization/wet spinning and solution polymerization/wet spinning. Refer to Figures 3-1 and 3-2 which are block and schematic diagrams of the suspension process model plant. Also refer to Figures 3-3 and 3-4 which represent the solution process model plant. Emissions sources are indicated by numbers in brackets (e.g. [2]) on the flowsheets. This convention is carried into text, and a number in brackets refers to the emission source shown on the flowsheet.

3.2 SUSPENSION POLYMERIZATION/WET SPINNING

Acrylonitrile and other monomers are pumped from storage to a monomer mix tank and then to the polymerization reactors. Water containing suspending agents, stabilizers and catalyst is added to the reactor monomer feed. The reactors are jacketed for reaction heat removal and agitated to maintain the monomers in a suspension in water. Polymerization proceeds in the presence of a catalyst and insoluble beads of polymer are formed. Reactor effluent is transferred to a vacuum flash tank to enhance release of most (80%) of the unreacted AN. Other monomers are reacted to virtual extinction.

The suspension is then pumped to the top of the slurry stripper (Option 1) where almost all of the remaining AN is stripped overhead by countercurrent contact with steam. Stripper bottoms is pumped to the first of two rotary vacuum filters. These units serve to concentrate the polymer in a cake to reduce the load in the dryers. They also remove most of the remaining AN from the polymer. Filter cake from the first filter is reslurried with water and transferred to the second filter. Reduced pressure is maintained in the filters by vacuum pumps. Filtrate (containing some AN) is transferred to the AN stripper feed tank. Filter cake from the second filter is sent to a pelletizer (optional) and then to a dryer where steam heated air is used to dry the polymer. Dry polymer is stored in bins or silos. Gas emissions from the process are slurry stripper overhead [1], reslurry tank vent [2], pelletizer vent [3], and dryer vent [4].

AN recovery is accomplished by use of an absorber/stripper system. AN containing gases from the reactors, vacuum flash tank, filter feed tank, recovered AN tank, decanters, stripper feed tank, filters and pelletizer are scrubbed with water in the AN absorber. Absorber overhead [5], is vented to the atmosphere. Bottoms from the absorber is joined by filtrate and is pumped to the top of the AN stripper. AN is steam stripped overhead along with a considerable amount of water. An overhead condenser is followed by a decanter where phase separation occurs. The water-rich phase is returned to the stripper and the AN-rich phase is recycled to the polymerization reactors through the tank for recovered AN. Stripper bottoms is sent to waste water treatment.

Dry polymer from storage is mixed with solvent and dissolved to form spinning dope which is filtered, deaerated and then pumped to the spinnerets. Dope is extruded into the spinning bath, that contains solvent diluted with water, causing the fibers to coagulate. Residual solvent remaining on the fibers after spinning (about 10% of the fiber weight) is removed by extraction with water. The fibers are stretched, dried, crimped and thermally stabilized. They may be cut into staple and baled or left uncut and sold as tow.

Gas emission streams from the process are solvent recovery scrubber overhead [6], crimper exhaust [7], and setting dryer exhaust [8]. The solvent recovery section of the plant collects and concentrates solvent recovered in the spinning and washing baths. A solvent recovery scrubber uses water to remove solvent from gas streams from spinning, washing and drying. Scrubber bottoms (solvent diluted with water) is also treated in solvent recovery. A typical solvent recovery system will consist of three distillation columns. The first concentrates the solvent by distilling water overhead. The second distills water and light ends overhead and produces concentrated solvent at or near the bottom. The third treats the overhead from the second and serves to separate light ends from water. Heavy ends which tend to build up in the system can be removed by distilling a portion of the second column bottoms in a tar still.

3.3 SOLUTION POLYMERIZATION/WET SPINNING

Acrylonitrile and other monomers are pumped from storage to a monomer mix tank where they are dissolved in a solvent. The monomer/solvent solution is transferred to the polymerization reactors where addition of an initiator causes the reaction to proceed. The PAN formed is soluble in the solvent. Reactor effluent is flashed to release most (80%) of the unreacted AN (41).

The solution is then pumped to the top of the stripper (Option 1) where virtually all of the remaining AN is stripped overhead by countercurrent contact with steam. Stripper overhead [1], is vented to the atmosphere.

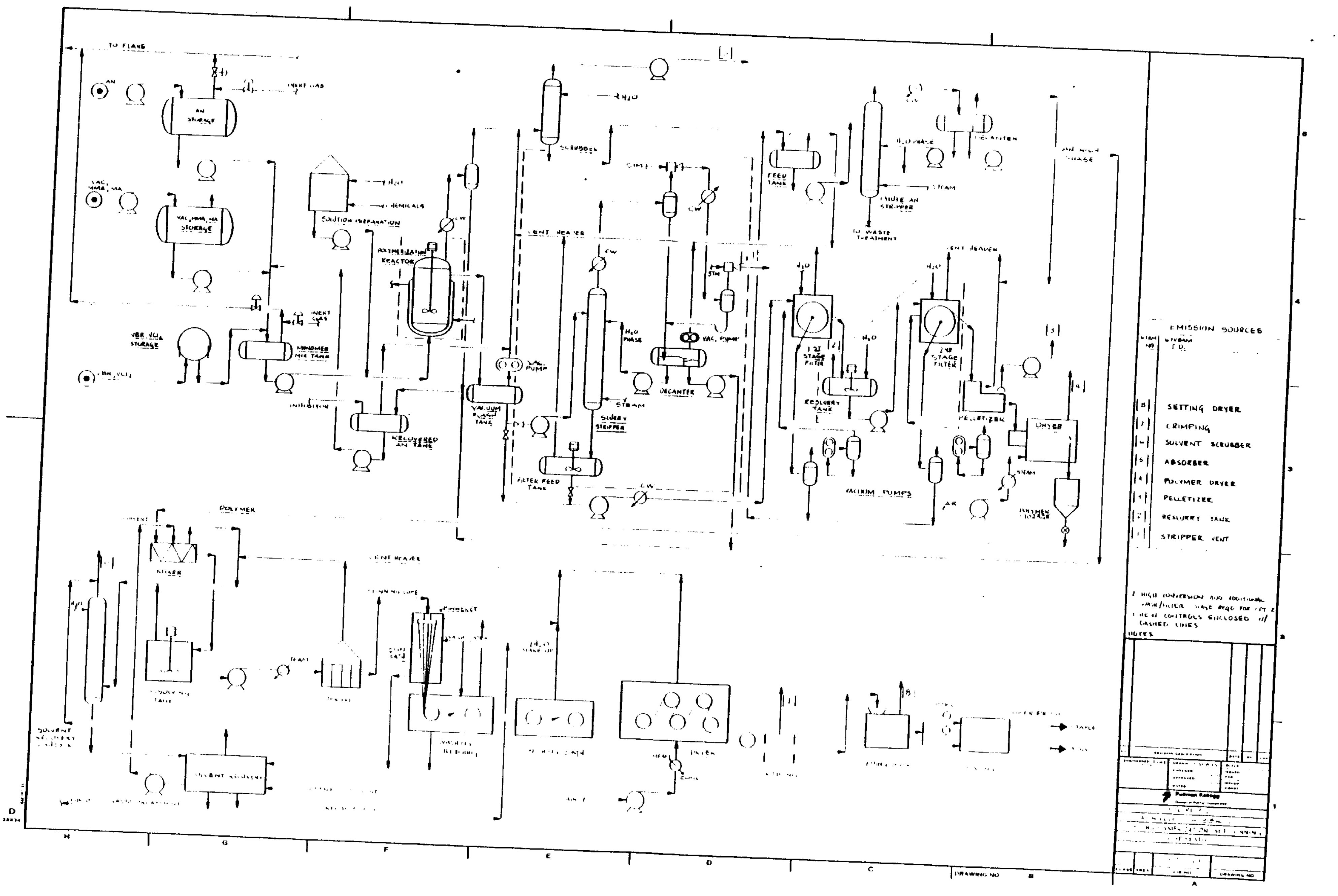
An absorber/stripper system is used to recover unreacted AN. AN containing gases from storage, the reactors, and the vacuum flash tank are scrubbed with water in the AN absorber. Absorber overhead is contacted with water in the vent scrubber. Overhead from this vessel [2], is vented to the atmosphere. Bottoms from the absorber is joined by AN-containing condensate from the vacuum flash condensers and pumped to the AN stripper. AN is steam stripped overhead along with some water. Overhead flows through a condenser to a decanter where phase separation occurs. The water-rich phase is returned to the stripper or sent to the monomer mix tank and the AN-rich phase is returned to the polymerization reactors through the recovered AN tank. Net water input to the system is removed from the stripper bottoms and sent to waste water treatment.

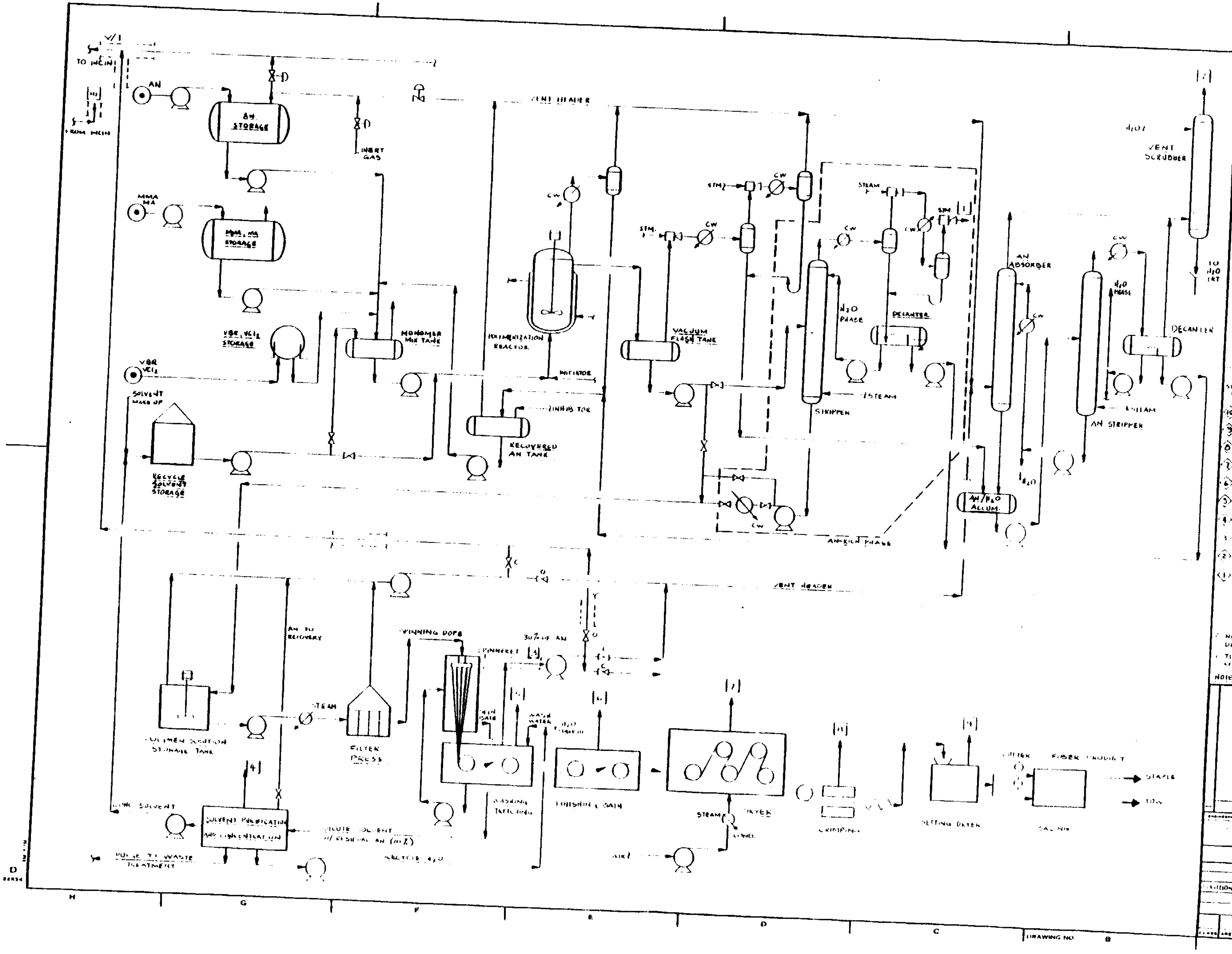
Stripped polymer solution is heated, filtered, deaerated and pumped to the spinnerets. Spinning dope is extruded into the spinning bath, composed of solvent diluted with water causing the polymer fibers to coagulate. The fibers are washed extensively with water to remove solvent and residual AN monomer from them.

A large portion (about 70%) of the unreacted AN monomer is washed from the fibers and returned to solvent purification with dilute solvent. From here it is vented to the AN recovery system (41). The remaining 30% of the residual AN is vented to the atmosphere from spinning and washing [3]. The fibers are then stretched, dried, crimped, thermally stabilized, cut into staple and baled or left uncut as tow.

Other atmospheric emissions of minor significance occur at stretching [5], the finishing bath [6], the fiber dryer [7], crimping [8], and the setting dryer [9].

The solvent purification section concentrates dilute solvent recovered from the spinning and washing steps for recycle to the polymerization reactors. This section also separates an AN containing gas stream which is sent to the AN absorber. A minor stream [4] is vented to the atmosphere.


TO FLARE
AN
INERT GAS
AN STORAGE
VAC, MMA, MA
VAC, MMA, MA STORAGE
VBR VCl2 STORAGE
VBR VCl2
INERT GAS
MONOMER MIX TANK
INHIBITOR
H2O
CHEMICALS
SOLUTION PREPARATION
POLYMERIZATION REACTOR
CW
RECOVERED AN TANK
SCRUBBER
H2O
VENT HEADER
VAC. PUMP
VACUUM FLASH TANK
FILTER FEED TANK
CW
SLURRY STRIPPER
H2O PHASE
STEAM
CW
DECANTER
VAC. PUMP
STM
FEED TANK
DILUTE AN STRIPPER
TO WASTE TREATMENT
STEAM
H2O PHASE
DECANTER
AN RICH PHASE
H2O
1ST STAGE FILTER
RESLURRY TANK
H2O
2ND STAGE FILTER
VENT HEADER
PELLETIZER
DRYER
STEAM
VACUUM PUMPS
AIR
POLYMER STORAGE
EMISSION SOURCES
ITEM NO
STREAM I.D.
8 SETTING DRYER
7 CRIMPING
6 SOLVENT SCRUBBER
5 ABSORBER
4 POLYMER DRYER
3 PELLETIZER
2 RESLURRY TANK
1 STRIPPER VENT
2 HIGH CONVERSION AND ADDITIONAL WASH/FILTER STAGE REQD FOR OPT 2
1 NEW CONTROLS ENCLOSED W/ DASHED LINES
NOTES
POLYMER
SOLVENT
MIXER
VENT HEADER
H2O
SOLVENT RECOVERY
SOLVENT RECOVERY
EFFLUENT
STEAM
H2O MAKE UP
DRIER
Pullman Kellogg
DRAWING NO
CLASS
AREA
A
B
C
D
E
F
G
H



EMISSION SOURCES

STRM. NO	STREAM I.D.
⟨10⟩	INCINERATOR
⟨9⟩	SETTING DRYER
⟨8⟩	CRIMPING
⟨7⟩	FIBER DRYER
⟨6⟩	FINISHING BATH
⟨5⟩	STRETCHING
⟨4⟩	SOLVENT PURIFICATION
⟨3⟩	SPINNING, WASHING VENT
⟨2⟩	SCRUBBER VENT
⟨1⟩	STRIPPER VENT

1. NEW CONTROLS ENCLOSED W/ DASHED LINES
2. TIGHT ENCLOSURE FOR SPINNING, WASHING REQUIRED W/ POLY. SOLUTION STRIPPING

NOTES

REVISION DESCRIPTION | DATE | BY | CHK

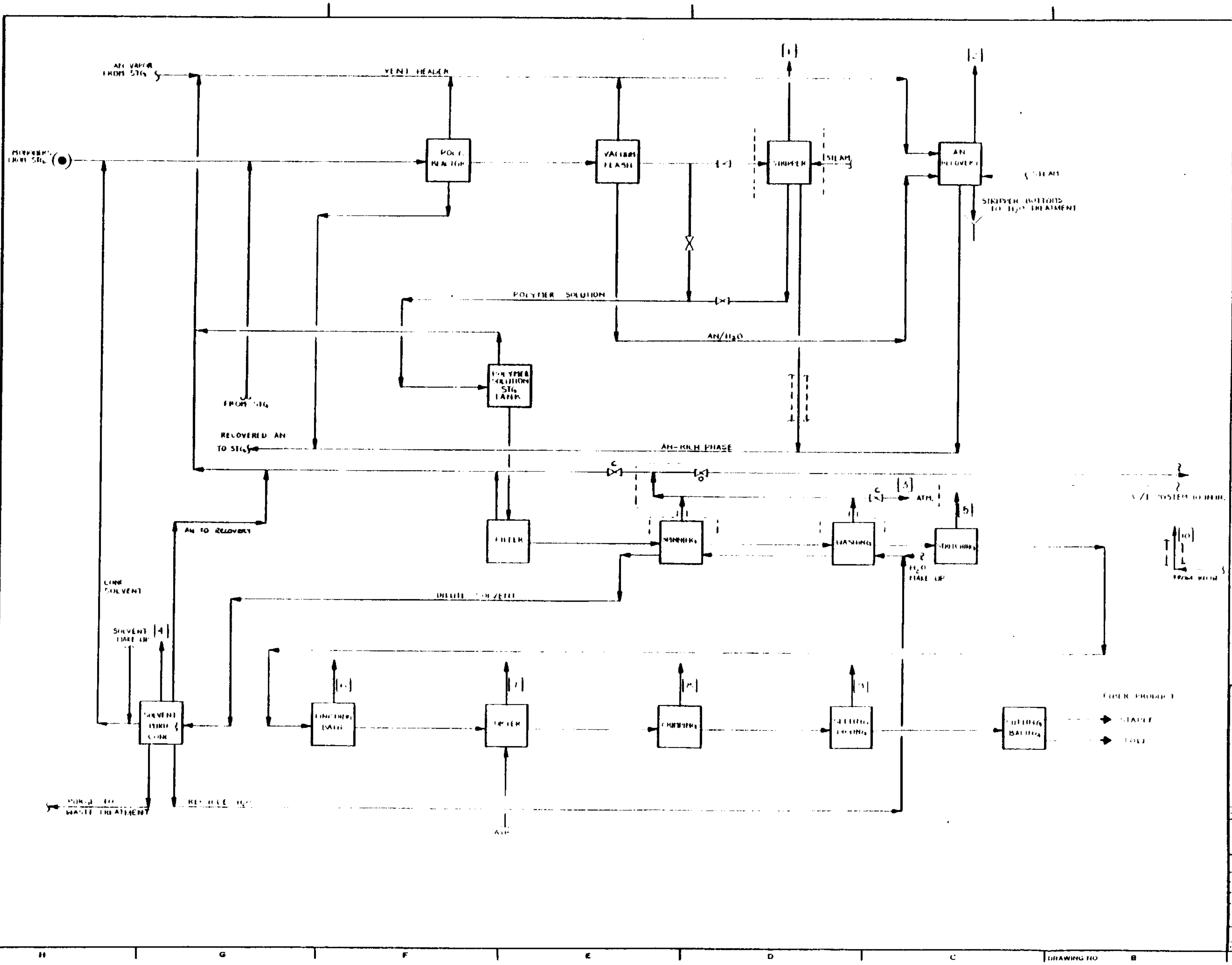
ENGINEERING | DRAWN J. [illegible] | CHECKED | APPROVED | DATED

SCALE | ISSUED | FOR | ISSUED | CHANGE

Pullman Kellogg
Division of Pullman Incorporated

FIGURE 3-4
ACRYLIC FIBERS
SOLUTION POLYMERIZATION WET SPINNING
SCHEMATIC

CLASS | AREA | 415/10 JOB NO | DRAWING NO



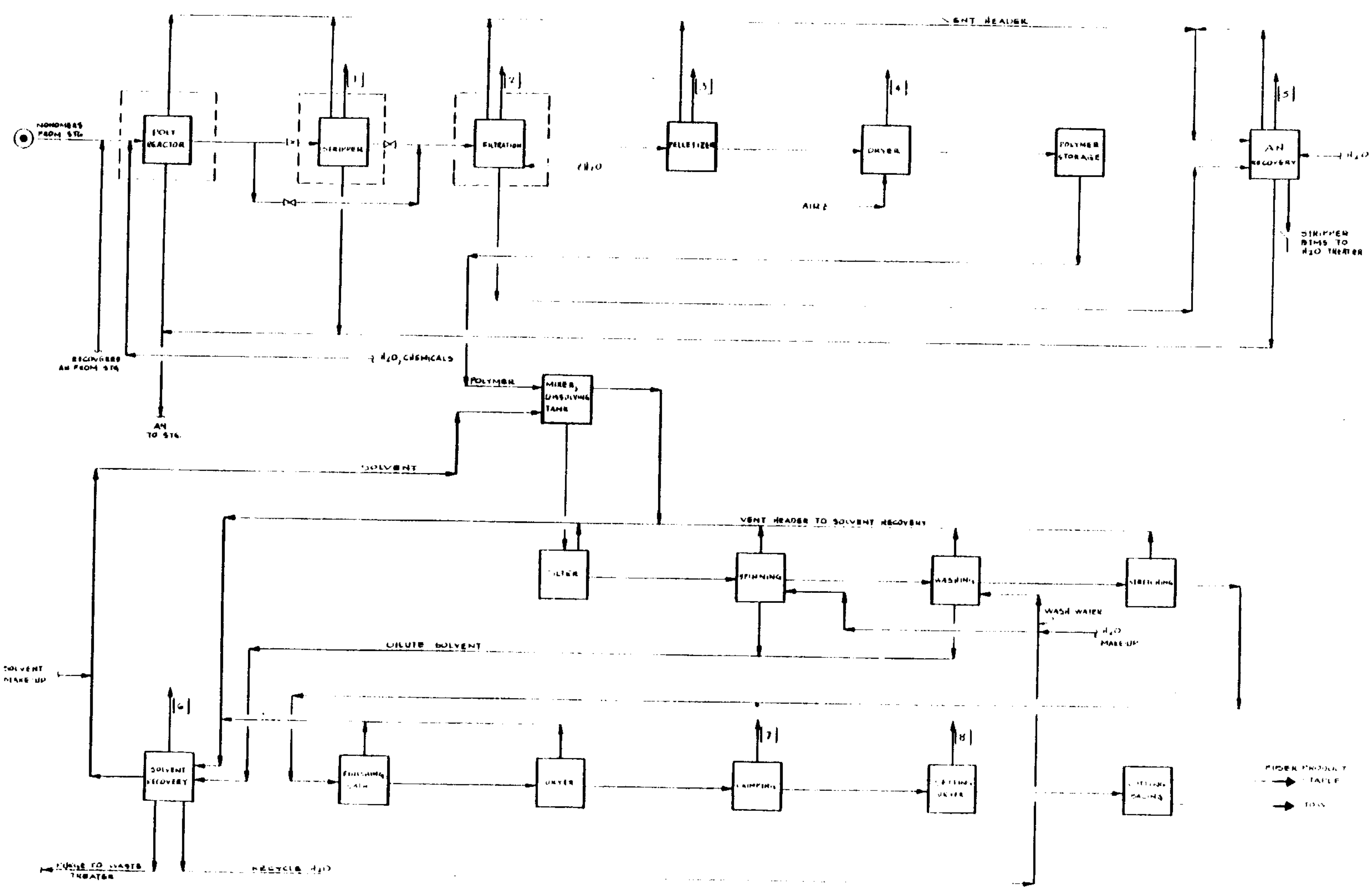
NOTES:
1. THE CONTROL EQUIP ENCLOSED IN DASHED LINES
2. ENCLOSURES AND INCINERATOR REQD FOR OPTION 2

Pullman Kellogg

FIGURE 3-3
ACRYLIC FIBERS
ADDITION POLYMERIZATION WET/SPINNING
BLOCK FLOW DIAGRAM

DRAWN	CHECKED	APPROVED	DATED	SCALE
DDM	F. DUNHAM			

CLASS	AREA	JOB NO	DRAWING NO
		41 3/ 10	



2 HIGH CONVERSION AND ADDITIONAL WASH/FILT STEPS REQUIRED WITHOUT STRIPPING.

1 NEW CONTROL EQUIPMENT ENCLOSED WITH DASHED LINES

NOTES

NO.	REVISION DESCRIPTION	DATE	BY	CHK

ENGINEERED DJM
DRAWN J GRAYS
CHECKED
APPROVED
DATED
SCALE

Pullman Kellogg

FIGURE 3.1

ACRYLIC FIBERS

SUSPENSION POLYMERIZATION/WET SPINNING

PROCESS FLOW DIAGRAM

CLASS	AREA	JOB NO	DRAWING NO
		413710	

SECTION 4

BDCT FOR MODEL PLANTS/CONTROL OPTIONS

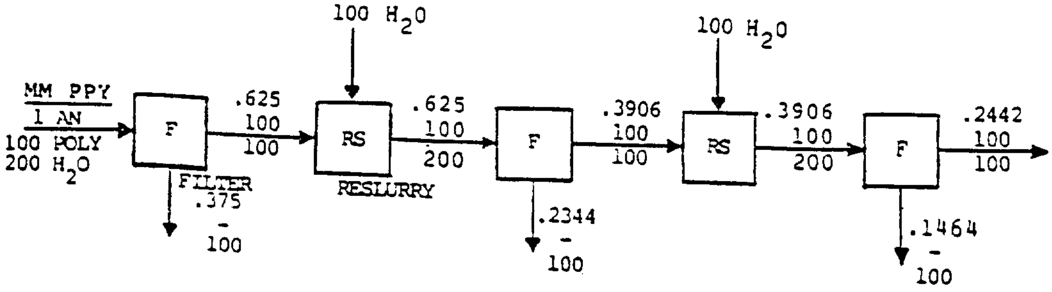
4.1 SUSPENSION POLYMERIZATION/WET SPINNING

The controls used in the various options are summarized below:

	Option 1	Option 2
Slurry Stripping	X	-
High Conversion Reactor	-	X
Additional Wash/Filter Stage	-	X

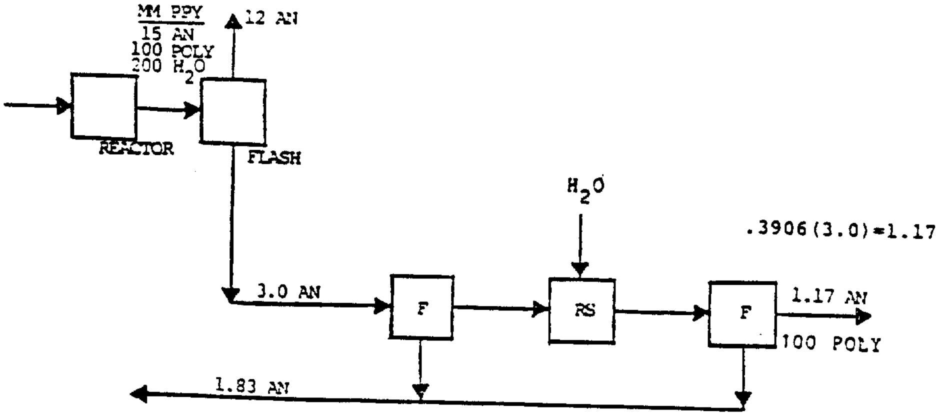
4.1.1 Uncontrolled Plant

The filter/wash system is shown in the following sketch. At each filter stage, 25% of the AN is assumed to be bound to the polymer, leaving the remainder to be distributed in the cake water and filtrate. At each reslurry step, wash water is added in an amount equal to the cake water. These assumptions result in a 37.5% AN removal per stage.



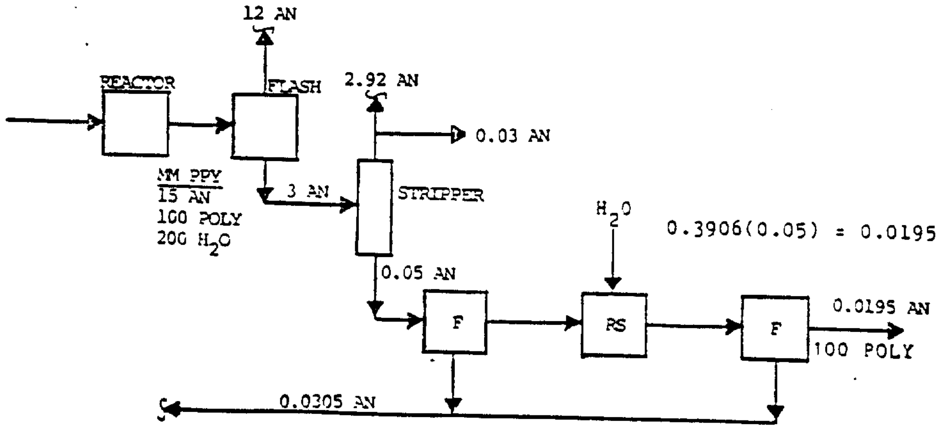
AN remaining after two filter steps (base plant) is shown to be $(0.625)^2 = 0.3906$ or 39.06% while that remaining after three filter stages (Option 2) is $(0.625)^3 = 0.2442$ or 24.42%.

The uncontrolled plant with a flash step and two filter stages is shown below. The suspension leaving the reactor contains 5 wt % AN in a 33.3% solids slurry which is vacuum flashed to release 80% of the unreacted AN. The filter steps remove 60.94% of the remaining AN leaving 1.17 MM PPY AN in the polymer which results in an uncontrolled emission of 11.7 lb AN/1000 lb product.



4.1.2 Option 1 - Suspension Stripping

Suspension from the reactor is flashed under vacuum to release 80% of the unreacted AN to the recovery system. The stream is then sent to the stripper where AN is stripped overhead by countercurrent steam flow. Stripper bottoms contain 500 ppm (wt-dry) AN which is sent to a standard two-stage rotary vacuum filter system with a reslurry step in between. About 61% of the AN is transferred from the polymer to the filtrate which is sent to AN recovery. About 195 ppm (wt-dry) AN remains in the filter cake which goes to downstream processing, and results in an emission of 0.2 lb AN/1000 lb product. Most of the AN is released at the polymer dryer, and the remainder is released at the pelletizer and the fiber treatment steps (crimping). Total AN process emissions are 0.2 plus 0.3 (stripper vent) or 0.5 lb/1000. Inclusion of a stripper (Option 1) which reduces AN to 500 ppm (wt-dry) results in the following distribution of AN.

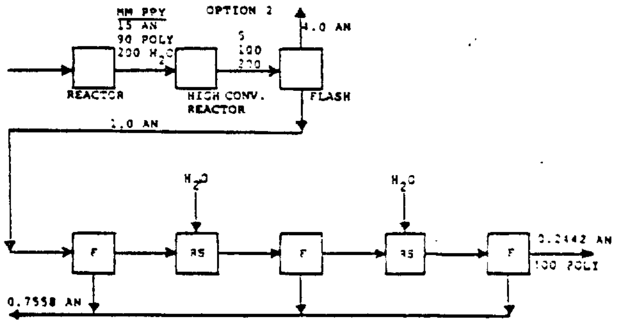


Additional AN recovery is (1.17 - 0.0195 - 0.03) = 1.12 MM PPY or 140 lb/hr.

4.1.3 Option 2 - High Conversion Reactor and Additional Wash/Filter Stage

An additional reactor is employed to obtain about 95% conversion of AN to PAN. Reactor effluent is flashed to release 80% of the unreacted AN to the recovery system. Slurry is then sent to the filter system where an additional wash/filter step has been added. About 75% of the remaining AN is transferred to the filtrate for recovery leaving 2442 ppm (wt-dry) in the polymer resulting in an emission of 2.44 lb AN/1000 lb product.

Option 2 using a high conversion reactor (95%) and an additional was/filter stage results in this distribution of AN.



Additional AN recovery is (1.17 - 0.2442) = 0.9258 MM PPY or 115.7 #/hr.

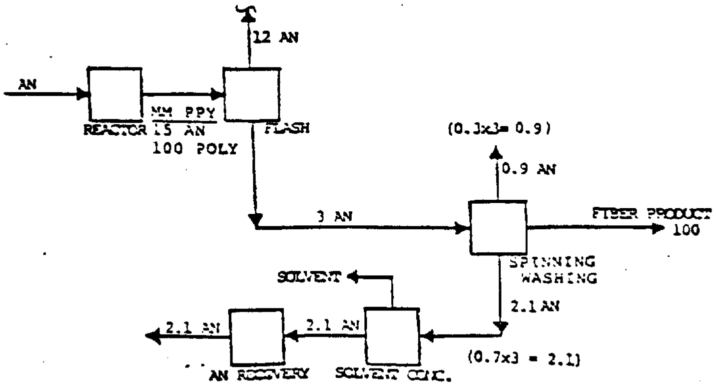
4.2 SOLUTION POLYMERIZATION/WET SPINNING

The controls used in the two options discussed here are:

	Option 1	Option 2
Solution Stripping	X	-
Enclosures for Spinning & Washing with Duct	-	X
Incinerator	-	X

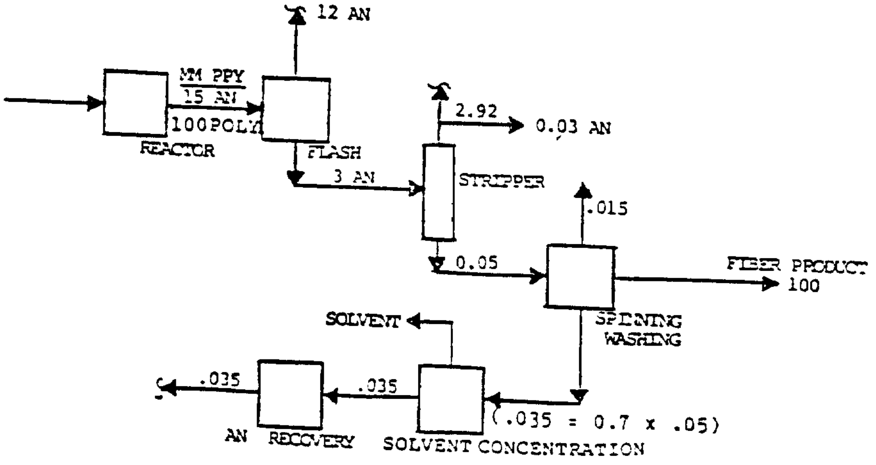
4.2.1 Uncontrolled Plant

The uncontrolled plant with a flash step and AN recovery from dilute solvent is shown below. The emission from this plant is expected to be 9 lb AN/1000 lb product.



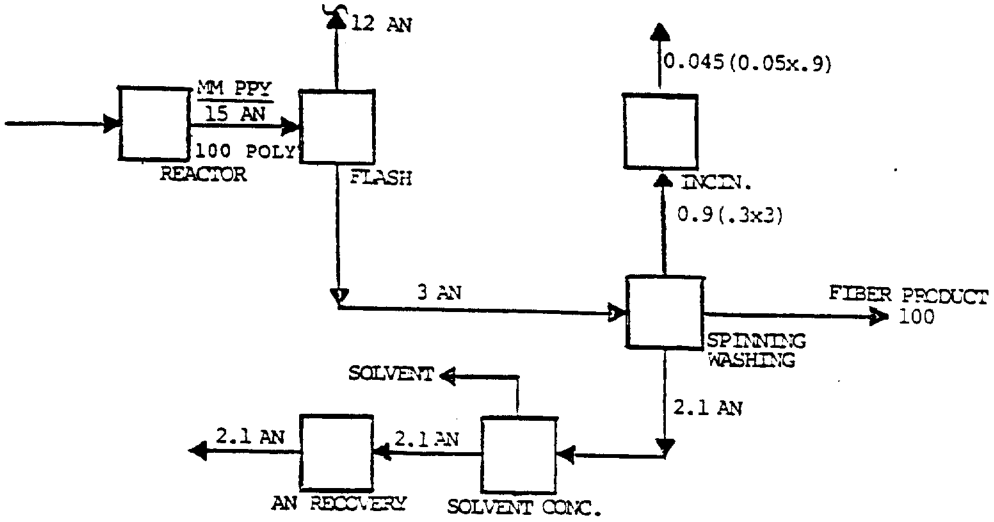
4.2.2 Option 1 - Solution Stripping

Solution from the reactor is flashed under vacuum to release 80% of the unreacted AN to recovery. It is then sent to the stripper where AN is stripped overhead by steam. Stripper bottoms contains 500 ppm (wt-dry) AN which is sent to spinning. About 70% of the remaining AN is removed with dilute solvent from the spinning and washing steps and sent to solvent concentration. From there it is sent to AN recovery. The remaining 30% is emitted to the atmosphere. Expected AN process emissions are about 0.45 lb/1000 lb product. Inclusion of a stripper (Option 1) results in this distribution of AN.



4.2.3 Option 2 - Enclosure of Spinning/Washing and Incineration

Since major AN emissions occur at spinning and washing, an alternate strategy for AN emission control is to use enclosures for these steps, with the collected gases being directed to an incinerator. The enclosures should be reasonably tight in order to limit the volume of gas to be treated. If a flow of 20,000 scfm is used, the AN concentration can be maintained at 5 to 10% of its lower explosive limit (3.05 vol%). Assuming an incinerator efficiency of 95%, the major process emission point will be the stack from this unit at 0.45 lb AN/1000 lb product. The system is shown below.



SECTION 5

EMISSIONS FROM MODEL PLANTS

5.1 SUSPENSION POLYMERIZATION

Uncontrolled model plant emissions as well as emissions for the various options are shown in Table 5-1.

5.1.1 Option 1 - Slurry Stripping

Using slurry stripping and the existing two-stage filter system reduces AN emissions from an uncontrolled value of about 11.7 lb AN/1000 to 0.5 lb/1000. VOC emissions (mostly spinning solvent) are reduced by about 50% with the use of a solvent scrubber on the vent gases from spinning, washing, and drying.

5.1.2 Option 2 - High Conversion and Additional Wash/Filter Stage

Employing a high conversion reactor and an additional wash/filter stage reduces AN emissions to 2.4 lb/1000. VOC emissions are reduced in a fashion similar to that previously mentioned.

5.2 SOLUTION POLYMERIZATION

Table 5-2 tabulates the emissions for solution polymerization for both options and for the uncontrolled model plant.

TABLE 5-1 - ACRYLIC FIBERS - SUSPENSION POLYMERIZATION EMISSIONS*

		Uncontrolled			Option 1			Option 2		
		lb/1000 lb			lb/1000 lb			lb/1000 lb		
Stream No.	Description	AN	VOC	TOTAL	AN	VOC	TOTAL	AN	VOC	TOTAL
1	Stripper Vent	-	-	-	0.3	0	0.3	0	0	0
2	Reslurry Tank	0	0	0	0	0	0	0	0	0
3	Pelletizer	1.15	0	1.15	0.02	0	0.02	0.25	0	0.25
4	Polymer Dryer	10.5	0	10.5	0.13	0	0.13	2.10	0	2.10
5	Absorber Vent	0	0	0	0	0	0	0	0	0
6	Solvent Scrubber Vent	0	1	1	0	1	1	0	1	1
7	Crimping	0.05	4	4.05	0.05	4	4.05	0.05	4	4.05
8	Setting Dryer	0	5	5	0	5	5	0	5	5
	TOTAL	11.7	10	21.7	0.5	10	10.5	2.4	10	12.4

*Distribution is approximate

TABLE 5-2 - ACRYLIC FIBERS - SOLUTION POLYMERIZATION EMISSIONS

		Uncontrolled lb/1000 lb			Option 1 lb/1000 lb			Option 2 lb/1000 lb		
Stream No.	Description	AN	VOC	TOTAL	AN	VOC	TOTAL	AN	VOC	TOTAL
1	Stripper Vent	-	-	-	0.3	0	0.3	-	-	-
2	Scrubber Vent	0	0.1	0.1	0	0.1	0.1	0	0.1	0.1
3	Spinning, Washing Vent	9	0.9	9.9	0.15	0.9	1.05	9*	0.9	9.9
4	Sol. Purif. Vent	0	0	0	0	0	0	0	0	0
5	Stretching	0	0	0	0	0	0	0	0	0
6	Finishing Bath	0	0	0	0	0	0	0	0	0
7	Fiber Dryer	0	0	0	0	0	0	0	0	0
8	Crimping	0	0	0	0	0	0	0	0	0
9	Setting Dryer	0	0	0	0	0	0	0	0	0
10	Incinerator In/ Out	0	0	0	-	-	-	9/ 0.45	1/ 0.05	10/ 0.5
	TOTAL	9.0	1.0	10.0	0.45	1	1.45	0.45	0.15	0.6

*To incinerator

5.2.1 Option 1 - Stripping

Solution stripping (along with recovery of 70% of the AN in the spinning dope) reduces AN emissions from an uncontrolled value of about 9 lb/1000 to 0.45 lb/1000. VOC emissions are expected to be very low with this process. Only about 1 lb/1000 will be lost to the atmosphere - mostly from spinning and washing [3].

5.2.2 Option 2 - Incineration

Enclosure of the spinning and washing equipment with collected gases being incinerated reduces AN and VOC emissions to 0.45 and 0.15 lb/1000 lb product respectively.

SECTION 6
ECONOMICS

6.1 ESTIMATED CAPITAL INVESTMENT COST FOR BDCT APPLIED TO MODEL PLANTS

Estimated capital investment costs (basis 1978) for the various control options based on 100 MM PPY are given below:

	Suspension Poly		Solution Poly	
	Option 1	Option 2	Option 1	Option 2
	Stripping	Addl. Reactor Wash and Filter	Stripping	Enclosures And Incineration
Capital Investment: MM$	2.75	2.60	2.75	2.234

For details of the investment estimate, see Part I and Appendix D.

6.2 OPERATING COST AND COST EFFECTIVENESS

Annual operating costs for the two control options for each case are given in the following tables.

TABLE 6-1.- SUSPENSION STRIPPING - OPTION 1

OPERATING HOURS/YEAR	8000	
SYSTEM PROPOSED	100 MM PPY Acrylic Fiber Production Suspension Stripping - Option 1	
CAPITAL COST		$2,750,000
OPERATING COST		
FIXED COSTS		
Depreciation	: 10% Capital	275,000
Interest	: 10% Capital	275,000
Taxes & Insurance	: 3% Capital	82,500
Overhead	: 7% Capital	192,500
Total Fixed Costs		825,000
VARIABLE COSTS		
Utilities		
Steam	: lb/hr @ $2.50/1000 lb	
CW	: GPM @ $0.05/1000 gal	
Power	: KW @ $0.025/KWH	
Fuel	: MM BTU/hr @ $2.50/MM BTU	
Total Utilities		150,000
Chemicals		
AN Recovered	: 140 lb/hr @ $0.27/lb	(302,400)
Total Chemicals		(302,400)
Operating Labor		
Labor	: 0.5 men/shift @ $108,000 ea.	54,000
Foremen & Supervision	: 25% labor cost	13,500
Total Direct Labor		67,500
Maintenance	: 3% Capital	82,500
Annualized Cost		822,600

TABLE 6-2. SUSPENSION POLYMERIZATION - OPTION 2

OPERATING HOURS/YEAR	8000	
SYSTEM PROPOSED	100 MM PPY Acrylic Fiber Production Suspension Poly - Option 2 Addl Reactor & Wash/Filter Stage	
CAPITAL COST		$2,600,000
OPERATING COST		
FIXED COSTS		
Depreciation	: 10% Capital	260,000
Interest	: 10% Capital	260,000
Taxes & Insurance	: 3% Capital	78,500
Overhead	: 7% Capital	182,000
Total Fixed Costs		780,000
VARIABLE COSTS		
Utilities		
Steam	: 3000 lb/hr @ $2.50/1000 lb	60,000
CW	: GPM @ $0.05/1000 gal	-
Power	: 500 KW @ $0.025/KWH	100,000
Fuel	: MM BTU/hr @ 2.50/MM BTU	-
Total Utilities		160,000
Chemicals		
AN Recovered	: 115.7 lb/hr @ $0.27/lb	(250,000)
Total Chemicals		(250,000)
Operating Labor		
Labor	: 0.5 men/shift @ $108,000 ea.	54,000
Foremen & Supervision	: 25% labor cost	13,500
Total Direct Labor		67,500
Maintenance	: 5% Capital	130,000
Annualized Cost		887,500

TABLE 6-3.- SOLUTION STRIPPING OPTION 1

OPERATING HOURS/YEAR	8000	
SYSTEM PROPOSED	100 MM PPY Acrylic Fiber Production Solution Stripping - Option 1	
CAPITAL COST		$2,750,000
OPERATING COST		
FIXED COSTS		
Depreciation	: 10% Capital	275,000
Interest	: 10% Capital	275,000
Taxes & Insurance	: 3% Capital	82,500
Overhead	: 7% Capital	192,500
Total Fixed Costs		825,000
VARIABLE COSTS		
Utilities		
Steam	: lb/hr @ $2.50/1000 lb	
CW	: GPM @ $0.05/1000 gal	
Power	: KW @ $0.025/KWH	
Fuel	: MM BTU/hr @ 2.50/MM BTU	
Total Utilities		150,000
Chemicals		
AN Recovered	: 106.9 lb/hr @ $0.27/lb	(230,900)
Total Chemicals		(230,900)
Operating Labor		
Labor	: 0.5 men/shift @ $108,000 ea.	54,000
Foremen & Supervision	: 25% labor cost	13,500
Total Direct Labor		67,500
Maintenance	: 3% Capital	82,500
Annualized Cost		894,100

TABLE 6-4.- SOLUTION POLYMERIZATION - OPTION 2

OPERATING HOURS/YEAR	8000	
SYSTEM PROPOSED	100 MM PPY Acrylic Fiber Production Solution Poly - Option 2 Enclosed Spinning/Washing & Incineration	
CAPITAL COST		$2,234,000
OPERATING COST		
FIXED COSTS		
Depreciation	: 10% Capital	223,400
Interest	: 10% Capital	223,400
Taxes & Insurance	: 3% Capital	67,000
Overhead	: 7% Capital	156,400
Total Fixed Costs		670,200
VARIABLE COSTS		
Utilities		
Steam	: lb/hr @ $2.50/1000 lb	-
CW	: GPM @ $0.05/1000 gal	-
Power	: 150 KW @ $0.025/KWH	30,000
Fuel	: 4.1 MM BTU/hr @ 2.50/MM BTU	82,000
Total Utilities		112,000
Chemicals		
AN Recovered	: lb/hr @ $0.27/lb	-
Total Chemicals		
Operating Labor		
Labor	: 0.5 men/shift @ $108,000 ea.	54,000
Foremen & Supervision:	25% labor cost	13,500
Total Direct Labor		67,500
Maintenance	: 5% Capital	111,700
Annualized Cost		961,400

Total operating costs for the different cases are summarized in Table 6-5.

Table 6-5.- SUMMARY OF OPERATING COSTS

Capacity: 100 MM PPY

	Suspension		Solution	
	Option 1	Option 2	Option 1	Option 2
Total Annual Operating Cost:				
MM $/Yr.	0.8226	0.8875	0.8941	0.9614
¢/lb Product	0.823	0.888	0.894	0.961
$/lb AN Emission Prevented*	0.734	0.959	1.045	1.124

*Emission of AN prevented
Susp. Option 1 : 140 lb/hr
Option 2 : 115.7 lb/hr
Soln. Option 1 : 106.9 lb/hr
Option 2 : 106.9 lb/hr

For suspension polymerization, the estimated investment cost for Option 1 is slightly higher than for Option 2. This leads to somewhat higher fixed charges. However, greater AN recovery and lower maintenance more than offset this and the total annual operating cost is slightly lower for Option 1. Since more AN is recovered for Option 1, it is somewhat more cost effective; its cost per pound of AN emission prevented is lower.