

POLYESTER PROCESS USING A PIPE REACTOR

FIELD OF THE INVENTION

The invention relates to polyester processes using a pipe reactor and to
5 corresponding apparatuses. More particularly, the invention relates to processes and
to corresponding apparatuses including an esterification pipe reactor operated in an
upflow or downflow mode, especially in a regime including stratified flow.

BACKGROUND OF THE INVENTION

10 As the business of manufacturing polyesters becomes more competitive,
alternative processes have become highly desirable. Relevant background for this
invention is given in a U.S. patent application related to the present one and filed
the same day entitled "Polyester Process Using a Pipe Reactor" with the inventor,
Bruce Roger DeBruin.

15 Another related U.S. patent application filed the same day as the present
one and entitled, "Polyester Process Using a Pipe Reactor", with the inventors,
Bruce Roger Debruin and Daniel Lee Martin.

In addition are related cases U.S. Application Serial No. 10/013,318 filed
December 7, 2001 and U.S. Provisional Application Serial No. 60/254,040 filed
20 December 7, 2000.

SUMMARY OF THE INVENTION

It is an object of this invention to provide polyester processes using a pipe
reactor. Thus, this invention relates to a process for making a pre-polyester
25 comprising: providing an esterification pipe reactor comprising a pipe, the pipe
having an inlet and an outlet and constructed such that flow inside the pipe from the
inlet to the outlet follows a path that is not totally vertical nor totally horizontal;
and reacting one or more reactants flowing in the pipe towards the outlet under
esterification reaction conditions to form the pre-polyester.

30 The invention also relates to similar processes wherein the pipe is
constructed such that flow inside the pipe from the inlet to the outlet follows an

overall upward (outlet higher than inlet), but not totally vertical path; this path may be in addition generally non-downward, non-vertical.

Further, the invention relates to any of these processes wherein stratified flow appears in the pipe.

5 Similarly, the invention relates to a process for making a polyester oligomer, a polyester or both comprising: performing any of the aforementioned processes for making a pre-polyester; and reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

10 The invention also relates to processes corresponding to those described here wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall downward (outlet lower than inlet), but not totally vertical path; this path may be in addition generally non-upward, non-vertical.

15 A further object of this invention is to provide apparatuses for polyester processes using a pipe reactor. Thus, this invention relates to apparatuses corresponding to the processes described above.

BRIEF DESCRIPTION OF THE DRAWINGS

20 The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the invention and together with the description serve to explain the principles of the invention.

25 **FIG. 1** shows typical embodiments of the polyester processes and apparatuses of the present invention.

Key to Number Designations in Fig. 1

- 1 tank (optional)
30 1A line from tank to pipe (optional)
3 pipe inlet

- 5 pipe of esterification pipe reactor
- 7 vapor disengager (optional)
- 7A vapor line (optional)
- 9 recycle line (optional)
- 5 11 pipe outlet
- 15 polycondensation reactor (optional and shown as a pipe reactor)
- 15A line from polycondensation reactor to pipe (optional)

10 DETAILED DESCRIPTION OF THE INVENTION

In this disclosure and the claims that follow, unless otherwise indicated, the term polyester is used in a broad sense and refers to a polymer containing more than 100 ester linkages (or more than 100 corresponding linkages in the case of derivatives of "straight" or "pure" polyesters such as polyetheresters, polyester amides and polyetherester amides). Similarly, polyester monomers would have 1 to 15 2 such linkages, polyester dimers 3 to 4 such linkages, polyester trimers 5 to 6 such linkages and polyester oligomers 7 to 100 such linkages. Pre-polyester refers to polyester monomers, dimers, trimers, oligomers and combinations of these.

For simplicity, polyester processes will be understood to include processes 20 for making pre-polyesters when used in this disclosure and the claims that follow, unless indicated otherwise.

The processes according to the present invention include a process for making a pre-polyester comprising providing an esterification pipe reactor comprising a pipe, the pipe having an inlet and an outlet and constructed such that 25 flow inside the pipe from the inlet to the outlet follows a path that is not totally vertical nor totally horizontal; and reacting one or more reactants flowing in the pipe towards the outlet under esterification reaction conditions to form the pre-polyester.

More specifically, the pipe may be constructed such that flow inside the 30 pipe from the inlet to the outlet follows an overall upward (outlet higher than inlet),

but not totally vertical path; this path may be in addition generally non-downward, non-vertical. Further, the pipe may substantially empty; that is substantially free of mechanical or structural internals (reactants and the like not included of course). The pipe is understood to be hollow in the context of this disclosure and the claims that follow.

For simplicity, esterification is taken to include, throughout this disclosure and the claims that follow, not only its common meaning, but ester exchange as well.

The processes according to the present invention also include processes for making a polyester oligomer, a polyester or both comprising performing (the steps of) any of the processes for making a pre-polyester previously described and reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both. This last mentioned step of reacting under polycondensation reaction conditions may be carried out in a polycondensation pipe reactor or other type of reactor for polycondensation.

The reactions taking place as part of the processes according to the present invention ordinarily produce water (and perhaps other types of) vapor, which unless removed, may significantly reduce product yield. Thus, the processes of the present invention may further comprise removing vapor from inside the pipe.

Given space limitation normally present at manufacturing sites, it may be convenient for the pipe to be serpentine; that is, having at least one bend. One preferred orientation for the pipe in accordance with this is shown in Fig. 1. The pipe 5 has several horizontal zones joined by bends.

In the reaction systems covered by the processes of the present invention, there may be solubility problems involving one or more reactants. For example, terephthalic acid is not very soluble in ethylene glycol, thus making it difficult to get the two to react in making polyethylene terephthalate. Thus, the processes of the present invention may further comprise adding a solubilizing agent into the pipe. For purposes here, a solubilizing agent makes one or more reactants more

soluble in the other(s) or the reaction mixture generally; in this context (in reference to solubilizing agents), reactants will be taken as only those that are precursors for polyester monomers (as solubilizing agents are not such precursors). Suitable solubilizing agents include those comprising a polyester monomer, dimer and/or trimer; those comprising a polyester oligomer; those comprising a polyester; those comprising organic solvents such as chlorinated aromatics (like trichlorobenzene) and mixtures of phenol and chlorinated hydrocarbons (like tetrachloroethane), tetrahydrofuran or dimethyl sulfoxide; as well as those comprising combinations of these. Such agents comprising a polyester oligomer, especially of the type being produced in the process, are often preferred. These agents may be mixed with reactants prior to addition to the pipe or added to the pipe separately in whole or in part. If mixed with reactants (here polyester monomer precursors) in any way, the solubilizing agent would be considered to be the mixture less any such reactants.

Many different types of reactants or mixtures of reactants may be used in forming polyesters and pre-polyesters according to the processes of the present invention, the types or mixtures of reactants comprising a dicarboxylic acid (abbreviated here as a diacid), a diol, a diester, a hydroxy ester, a carboxylic acid ester (abbreviated here as an acid ester), a hydroxy carboxylic acid (abbreviated here as a hydroxy acid) or combinations thereof. It is possible that related materials such as tricarboxylic acids and other such multifunctional materials could also be employed. It should be understood that acid in this context would include corresponding mono, di or higher order salts. Of course, the pre-polyesters and polyesters being formed may be in turn reactants themselves.

More specific reactants or mixtures of reactants of interest comprise aromatic dicarboxylic acids preferably having 8 to 14 carbon atoms, aliphatic dicarboxylic acids preferably having 4 to 12 carbon atoms, or cycloaliphatic dicarboxylic acids preferably having 8 to 12 carbon atoms. Such comprise terephthalic acid, phthalic acid, isophthalic acid, naphthalene-2,6-dicarboxylic acid, cyclohexanedicarboxylic acid, cyclohexanediacetic acid, diphenyl-4,4'-dicarboxylic

acid, dipheny-3,4'-dicarboxylic acid, 2,2,-dimethyl-1,3-propandiol, dicarboxylic acid, succinic acid, glutaric acid, adipic acid, azelaic acid, sebacic acid, mixtures thereof, and the like. The acid component can be fulfilled by the ester thereof, such as with dimethyl terephthalate.

5 Further more specific reactants or mixtures of reactants comprise cycloaliphatic diols preferably having 6 to 20 carbon atoms or aliphatic diols preferably having 3 to 20 carbon atoms. Such comprise ethylene glycol (EG), diethylene glycol, triethylene glycol, 1,4-cyclohexane-dimethanol, propane-1,3-
 10 diol, butane-1,4-diol, pentane-1,5-diol, hexane-1,6-diol, neopentylglycol, 3-methylpentanediol-(2,4), 2-methylpentanediol-(1,4), 2,2,4-trimethylpentane-diol-(1,3), 2-ethylhexanediol-(1,3), 2,2-diethylpropane-diol-(1,3), hexanediol-(1,3), 1,4-di-(hydroxyethoxy)-benzene, 2,2-bis-(4-hydroxycyclohexyl)-propane, 2,4-dihydroxy-1,1,3,3-tetramethyl-cyclobutane, 2,2,4,4 tetramethylcyclobutanediol, 2,2-bis-(3-hydroxyethoxyphenyl)-propane, 2,2-bis-(4-hydroxypropoxyphenyl)-
 15 propane, isosorbide, hydroquinone, BDS-(2,2-(sulfonylbis)4,1-phenyleneoxy))bis(ethanol), mixtures thereof, and the like. Pre-polyesters and polyesters may be prepared from one or more of the above type diols.

Some preferred comonomers comprise terephthalic acid, dimethyl terephthalate, isophthalic acid, dimethyl isophthalate, dimethyl-2,6-
 20 naphthalenedicarboxylate, 2,6-naphthalenedicarboxylic acid, ethylene glycol, diethylene glycol, 1,4-cyclohexane-dimethanol (CHDM), 1,4-butanediol, polytetramethyleneglycol, trans-DMCD (trans-dimethyl-1,4-cyclohexane dicarboxylate), trimellitic anhydride, dimethyl cyclohexane-1,4-dicarboxylate, dimethyl decalin-2,6 dicarboxylate, decalin dimethanol, decahydronaphthalene 2,6-
 25 dicarboxylate, 2,6-dihydroxymethyl-decahydronaphthalene, hydroquinone, hydroxybenzoic acid, mixtures thereof, and the like. Bifunctional (A-B type where the ends are not the same) comonomers, such as hydroxybenzoic acid may also be included.

Some specific reactants or mixtures of reactants of very special interest
 30 comprise terephthalic acid (TPA; understood to include crude, purified (PTA) or

that in between), dimethyl terephthalate (DMT), cyclohexane dimethanol (CHDM), isophthalic acid (IPA), ethylene glycol (EG) or combinations thereof.

Many types of polyesters may be made using the processes of the present invention. Two of special interest are polyethylene terephthalate (PET) and PETG
5 (PET modified with CHDM).

Ranges stated in this disclosure and the claims that follow should be understood to disclose the entire range specifically and not just end points(s). For example, disclosure of the range 0 to 10 should be taken to specifically disclose 2, 2.5, and 3.17 and all other number subsumed in the range and not just 0 and 10.
10 Further a disclosure of C1 to C5 (one to five carbon) hydrocarbons would be a specific disclosure of not only C1 and C5 hydrocarbons, but also of C2, C3, and C4 hydrocarbons; ranges that are clearly meant to be ranges of integers should be understood correspondingly.

One area of intense interest regarding polyester processes using a pipe
15 reactor is the effect of flow regime in the pipe. Surprisingly, it has been determined that under many circumstances it may be desirable to operate the esterification pipe reactor, at least in part, in a stratified flow regime. Accordingly, the processes of the present invention include those previously described wherein stratified flow appears in the pipe (of an esterification pipe reactor). For this purpose, stratified
20 flow may be defined as a flow pattern in a pipe in which liquid flows along the bottom and vapor flows over a liquid-vapor interface. Pipe reactors can be designed by those of ordinary skill in the art to meet this criteria in operation by application of standard engineering design techniques with reference to the disclosures herein.

In the systems considered here, operation so that stratified flow appears in
25 the pipe will produce two, three or more phase systems.

Given different pipe designs, it may be desirable to operate with stratified flow in a certain given percentage or section(s) of the pipe. Calculations to determine needed parameters may be performed by those of ordinary skill in the art using standard engineering tools after consultation of the disclosures herein.

Esterification pipe reactors operated to produce liquid superficial velocities inside the pipe of less than 0.15 m/s and corresponding vapor superficial velocities less than 3.0 m/s, both across any full cross sectional area inside the pipe perpendicular to the (overall) flow path in the pipe (at that cross section) will in
 5 very many of the systems considered herein be in a stratified flow regime, at least in part. Even if not, the regime present should be acceptable. Thus, the processes of the present invention include those previously described wherein the liquid superficial velocity is less than 0.15 m/s (with one preferred range of 0.01 to 0.15 m/s for the liquid) and the vapor superficial velocity is less than 3.0 m/s (with one
 10 preferred range of 0.01 to 3.0 m/s and another of 0.6 to 3.0 m/s for the vapor) across any full cross sectional area inside the pipe perpendicular to the (overall) flow path in the pipe (at that cross section). (Of course, each phase must be moving at some point or there can be no stratified flow).

Given different pipe designs, it may be desirable to operate with superficial
 15 velocities as above in a certain given percentage or section(s) of the pipe. Calculations to determine needed parameters may be performed by those of ordinary skill in the art using standard engineering tools after consultation of the disclosures herein.

Two parameters of interest in the art relating to the present invention are the
 20 Baker plot parameters, B_x and B_y . These are defined as

$$B_x = (G_L \lambda \psi) / G_G, \text{ dimensionless and}$$

$$B_y = (G_G / \lambda), \text{ lb}/(\text{sec ft}^2)$$

25 where, $\lambda = (\rho'_c \rho'_L)^{1/2}$; $\psi = (1 / \sigma') (\mu'_L / (\rho'_L)^2)^{1/3}$; G_G = vapor mass velocity; G_L = liquid mass velocity; μ'_L = ratio of liquid viscosity to water viscosity, dimensionless; ρ'_c = ratio of vapor density to air density, dimensionless; ρ'_L = ratio of liquid density to water density, dimensionless; σ' = ratio of liquid surface
 30 tension to water surface tension, dimensionless; and air and water properties are at

20° C (68° F) and 101.3 kPa (14.7 lbf/in²). See Perry's Chemical Engineers' Handbook, 6th ed., pp 5-40 and 5-41.

Esterification pipe reactors operated such that B_x is less than 4.0 while B_y is less than 2.0 or B_x is greater than or equal to 4.0 while $(\log_{10} B_y)$ is less than or equal to $-0.677(\log_{10} B_x) + 0.700$ on average across any full cross sectional area inside the pipe perpendicular to the (overall) flow path in the pipe (at that cross section) will in very many of the systems considered herein be in a stratified flow regime, at least in part. Even if not, the regime present should be acceptable. Thus, the processes of the present invention include those previously described wherein B_x is less than 4.0 while B_y is less than 2.0 or B_x is greater than or equal to 4.0 while $(\log_{10} B_y)$ is less than or equal to $-0.677(\log_{10} B_x) + 0.700$ on average across any full cross sectional area inside the pipe perpendicular to the (overall) flow path in the pipe (at that cross section).

Given different pipe designs, it may be desirable to operate with B_x and B_y as above in a certain given percentage or section(s) of the pipe. Calculations to determine needed parameters may be performed by those of ordinary skill in the art using standard engineering tools after consultation of the disclosures herein.

The processes according to the present invention also include those corresponding to those described above wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall downward (outlet lower than inlet), but not totally vertical path and such path may be in addition generally non-upward, non-vertical.

The apparatuses according to the present invention include those corresponding to the processes of the present invention. In particular, an apparatus for making a pre-polyester comprising: an esterification pipe reactor comprising a pipe, the pipe having an inlet and an outlet and constructed such that flow inside the pipe from the inlet to the outlet follows a path that is not totally vertical nor totally horizontal, and wherein pre-polyester forming reactants are passed towards the outlet.

More specifically, the pipe may be constructed such that flow inside the pipe from the inlet to the outlet follows an overall upward, but not totally vertical path and this path may also be generally non-downward, non-vertical. The pipe may also be substantially empty (as defined previously).

5 The apparatuses according to the present invention also include those for making a polyester oligomer, a polyester or both comprising any of the apparatuses previously described and a polycondensation reactor connected to the outlet of the pipe; this last mentioned polycondensation pipe reactor may be a polycondensation pipe reactor or of any other type suitable for polycondensation.

10 In reference to the apparatuses of the present invention connected means directly or indirectly (through a bridging piece(s) of process equipment) in fluid communication.

 As discussed previously, it is often important to remove vapor from inside the pipe, so the apparatuses of the present invention may further comprise means
15 for removing vapor from inside the pipe at at least one point along the pipe. This point along the pipe could include the inlet or the outlet. In addition or instead of removal from the pipe, vapor could be removed outside of the pipe, generally and/or prior to polycondensation and/or during polycondensation. Means for such vapor removal include vapor disengagers, vents and other devices known in the art.
20 See Perry's Chemical Engineers' Handbook.

 Also as discussed previously, the pipe may be serpentine.

 One variation on the apparatuses of the present invention possible is the addition of a tank for holding solubilizing agent (which may be mixed with reactants (polyester monomer precursors here) if desired) that is connected to the
25 pipe at a point other than the outlet. Further, a recycle line connecting the pipe at a point nearer to the outlet than the inlet with the pipe at a point nearer the inlet than the outlet could be employed at least for addition of recycle as a solubilizing agent to the pipe. Similarly, a flow line from the polycondensation reactor to the pipe at a point other than the outlet could also be added.

The apparatuses according to the present invention also include those corresponding to those described above wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall downward, but not totally vertical path and such path may be in addition generally non-upward, non-vertical.

One special consideration for this last mentioned class of apparatuses according to the present invention is keeping the upper sections of the pipe from running dry when the pipe is serpentine. Thus, the apparatuses of the present invention include those further comprising means for removing vapor from the pipe at a least one bend and wherein the pipe is serpentine and has at least one weir at an effective distance from a bend. Means for vapor removal is as previously discussed. Effective distance for the weir refers to a hydraulically effective distance to achieve the objective of keeping the upper pipe sections from going totally dry; this can be determined by those of ordinary skill in the art using standard engineering methods following study of the disclosures herein.

Fig. 1 illustrates the apparatuses of the present invention as well as the corresponding processes. Optional tank 1 is for storage of solubilizing agent which may be mixed with reactants. It is connected (if present) by 1A to the pipe of the esterification pipe reactor 5. Pipe inlet 3 is where fresh reactants are ordinarily charged to the reactor and is a reference point for flow through the pipe 5. Pipe 5 is shown in a preferred orientation such that several horizontal sections are bridged by upward bends and the inlet 3 is below the pipe outlet 11 in elevation. During operation, reactants flow through the pipe 5 forming pre-polyester. Shown here near the pipe outlet 11 is an optional vapor disengager 7 and vapor line 7A for discharge of vapor from the flow in the pipe; as explained previously, vapor build up may negatively affect product yield in the reactor system. Flow through the pipe 5 leaves at the pipe outlet 11. Optionally, flow may be recycled through the recycle line 9. Flow from the pipe outlet 11 optionally enters the polycondensation reactor 15 (if present) which may be a polycondensation pipe reactor as shown. Optionally, some flow from the polycondensation reactor 15 may be sent to the pipe 5 through

the line 15A. Flows through 9 and 15A may act as solubilizing agents as discussed above.

Examples

5 The invention can be further illustrated by the following examples, but it should be understood that these examples are included merely for purposes of illustration and are not intended to limit the scope of the invention unless otherwise specifically indicated. Any titles in the examples are given for convenience and should not be taken as limiting.

Example 1

Using ASPEN modeling, exemplary volumes and pipe diameters were calculated for a commercial scale pipe reactor system for esterification of purified terephthalic acid (PTA) in ethylene glycol (EG). A SPEN Plus version 11.1 with Polymers Plus and ASPEN's PET Technology was used. The esterification reactor is modeled as a series of 5 CSTR reactor models followed by a plug flow reactor model. The results of the modeling and a pipe sizing for a stratified flow pipe reactor for esterification using polyester monomer recirculated from the exit to the entrance as a solubilizing agent for the feed PTA and taking off water vapor only at the end of the reactor length are shown in Table 1.

TABLE 1

Example:	Calculations for esterification in a single recirculating pipe reactor with vapor takeoff only at the end of the reactor	
PTA feed rate (lb/hr):		31320
Recirculation ratio (lbs of recirc/lb of product):		4.0
feed mole ratio (mole EG/mole PTA):		1.6
% conversion of acid end groups:		96%
Temperature (°C):		285
maximum pressure (psig):		52.1
recirculating reactor liquid volume (cu. ft):		2648
number of parallel pipes in reactor:		16
recirculating reactor pipe diameter (in):		16
recirculating reactor maximum liquid superficial velocity (ft/s):		0.03
recirculating reactor maximum vapor superficial velocity (ft/s):		9.8

Example 2

Using ASPEN modeling, exemplary volumes and pipe diameters were
5 calculated for a commercial scale pipe reactor system for esterification of purified
terephthalic acid (PTA) in ethylene glycol (EG). A SPEN Plus version 11.1 with
Polymers Plus and ASPEN's PET Technology was used. The esterification reactor
is modeled as a series of 5 CSTR reactor models followed by a plug flow reactor
10 model. The results of the modeling and a pipe sizing for a stratified flow pipe
reactor for esterification using polyester monomer recirculated from the exit to the
entrance as a solubilizing agent for the feed PTA are shown in Table 2. This
example shows the efficiency effects of a single vapor takeoff added in the middle
of the reactor length.

TABLE 2

Example:	Calculations for esterification in a single recirculating pipe reactor with vapor takeoff in the middle of the reactor and at the end of the reactor
PTA feed rate (lb/hr):	31320
Recirculation ratio (lbs of recirc/lb of product):	4.0
feed mole ratio (mole EG/mole PTA):	1.6
% conversion of acid end groups:	96%
Temperature (°C):	285
maximum pressure (psig):	52.1
recirculating reactor liquid volume (cu. ft):	1236
number of parallel pipes in reactor:	12
recirculating reactor diameter (in):	16
recirculating reactor maximum liquid superficial velocity (ft/s):	0.05
recirculating reactor maximum vapor superficial velocity (ft/s):	10.8

Example 3

5 Using ASPEN modeling, exemplary volumes and pipe diameters were
calculated for a commercial scale pipe reactor system for esterification of purified
terephthalic acid (PTA) in ethylene glycol (EG). A SPEN Plus version 11.1 with
Polymers Plus and ASPEN's PET Technology was used. The esterification reactor
is modeled as a series of 5 CSTR reactor models followed by a plug flow reactor
10 model. The results of the modeling and a pipe sizing for a series of stratified flow
pipe reactors for esterification using polyester monomer recirculated from the exit
of the first pipe reactor to the entrance of the first pipe reactor as a solubilizing
agent for the feed PTA are shown in Table 3. This example shows the optimization
effects of using recirculation only as required for solubility concerns and using plug
15 reaction profile with no recirculation as much as possible.

TABLE 3

	Calculations for single recirculating pipe reactor with two vapor takeoffs followed by plug flow pipe optimized for total volume
Example:	
PTA feed rate (lb/hr):	31320
Recirculation ratio (lbs of recirc/lb of product):	4.0
feed mole ratio (mole EG/mole PTA):	1.6
% conversion of acid end groups:	96%
Temperature (°C):	285
maximum pressure (psig):	52.1
recirculating reactor liquid volume (cu. ft):	318
plug flow reactor liquid volume (cu. ft):	353
number of parallel pipes in recirculating reactor:	8
recirculating reactor diameter (in):	16
recirculating reactor maximum liquid superficial velocity (ft/s):	0.07
recirculating reactor maximum vapor superficial velocity (ft/s):	5.5
number of parallel pipes in plug flow reactor:	6
plug flow reactor diameter (in):	12
plug flow reactor maximum liquid superficial velocity (ft/s):	0.03
plug flow reactor maximum vapor superficial velocity (ft/s):	1.8

5 **EXAMPLE 4** *Lab-Model Comparison*

Lab Scale Reactor

10 A lab scale esterification pipe reactor was built to demonstrate such
esterification of PTA and EG in a laboratory setting. The lab unit consisted of a
pipe reactor made of 664.75 inches of 0.5" 18 BWG stainless tubing heated by
electric tracing, a 1200 ml receiver with agitator for receiving the output of the pipe
reactor and acting as a disengagement zone to allow the removal of vapors, a
recirculating monomer gear pump which pumps liquid oligomer from the receiver
15 back into the inlet of the pipe reactor, and a PTA/EG paste feed system which feed
raw materials into the recirculating loop.

20 The reactor was started by charging a PTA based CHDM modified (2.5
weight percent) oligomer of approximately 96% conversion into the receiver
(C-01) and filling the pipe reactor with this oligomer in recirculating mode. After
recirculating the oligomer at temperature, a PTA/EG paste feed was introduced into
the recirculating flow. After the reactor reached steady state, samples were taken
from the C-01 receiver at a rate equal to the product generation rate .

25 These samples were analyzed for percent conversion by proton NMR
analysis to determine the extent of reaction that took place in the pipe reactor.
Percent Conversion based on Esters were determined by Proton NMR using a
Trifluoroacetic Anhydride Method.

30 Ten mg of the sample to be analyzed is dissolved in 1 ml of a solvent
mixture of chloroform-d with 0.05% Tetramethylsilane (TMS)/trifluoroacetic acid-
d/trifluoroacetic anhydride in a 72/22/8 volume ratio. The mixture is heated to
50°C and stirred as needed to completely dissolve the sample to be analyzed.

 The appropriate amount of the sample solution is transferred into a 5 mm
NMR tube and the tube is capped. The proton NMR signal is recorded using an
average of 64 signals collections. The NMR signal using a 600 MHz NMR and a

NMR pulse sequence is collected which gives quantitative proton NMR signals and also decouples the carbon 13 NMR frequencies. The NMR spectrum is analyzed by measuring the correct areas calculating the percent conversion of acid groups to ester groups by the areas and calculations below:

5 Areas between the following chemical shift points referenced to TMS are measured, and percent conversion calculated using the formula.

Area A = 7.92 ppm to 8.47 ppm

Area B = 5.01 ppm to a valley between 4.82 and 4.77 ppm

Area C = 4.82 ppm to a valley between 4.74 and 4.69 ppm

10 Area D = A valley between 4.28 ppm and 4.18 ppm to a valley
 between 4.10 and 4.16 ppm

Area E = A valley between 4.10 ppm and 4.16 ppm to a valley
 between 4.0 and 4.08 ppm

Area F = 8.6 ppm to 8.9 ppm

15 Area G = 7.55 ppm to 7.8 ppm

$$\text{Percent Conversion} = 100 * (B + (0.5 * C) + D + (0.5 * E)) / (A + F + G)$$

20 The samples were also analyzed by gas chromatograph for percent DEG by mass to determine the rate of the side reaction. The effect of residence time and recirculation ratio was seen by varying the feed rate of the paste.

Results from laboratory runs can be seen in Table 4 below.

Table 4

	Temp	Pressure	Recirc	Paste Feed	Feed	Measured	Measured
Experiment	(°C)	(psig)	Rate (lbs./hr)	Rate (lbs./hr)	Mole Ratio (EG/PTA)	% Conversion	weight % DEG
1	285	0	67	1	1.8	94.2%	1.1%
2	285	0	67	1	1.8	93.7%	1.1%
3	285	0	67	1	1.8	92.5%	1.4%
4	285	0	67	1.5	1.8	92.7%	1.0%
5	285	0	67	2	1.8	90.9%	0.6%
6	285	0	67	2.5	1.8	87.2%	0.7%
7	285	0	67	3	1.8	64.2%	0.2%
8	285	0	67	3.5	1.8	67.1%	0.6%
9	285	0	67	4	1.8	51.9%	0.3%
10	285	0	67	3.5	1.8	77.4%	0.3%

Model Comparison

An ASPEN model was used to simulate the lab apparatus previously described in this example. In this case, ASPEN 11.1 with Polymers Plus, and ASPEN's PET Technology was used for the modeling with a model configuration similar to the one described for examples 1-3. Neither model configuration nor software were significantly different from that used in examples 1-3. In order to correctly simulate the dissolution of PTA into the oligomer at different conditions in the lab, it was sometimes necessary to add dissolution kinetics to the model. Table 5 shows three comparisons of lab runs with the model without dissolution kinetics included; this model was found to be of reasonable accuracy when the experimental conditions resulted in completely dissolved PTA as in these runs. Table 5 also shows two examples of comparisons of lab runs with the model including the dissolution kinetics; this model including the dissolution kinetics closely matches the measured conversion when free PTA is present at the end of the lab scale pipe reactor as in these runs. Conversion is defined in this context as the percentage of reactive (acid if use PTA as here) end groups in the liquid phase that are esterified as measured at the outlet of reactor.

TABLE 5

Completely Dissolved PTA - No Dissolution Kinetics in Model

Paste feed (g/min)	Monomer Circulation (g/min)	Temp. °C	Paste Mole Ratio (EG/PTA)	Unreacted PTA Weight %	Model Predicted % Conversion	Measured % Conversion
8	507	263.2	1.8	0.00	97.053	95.170
8	507	253.9	1.8	0.00	96.645	93.750
15	507	265.5	1.8	0.00	96.269	91.630

PTA Not Completely Dissolved/Dissolution in Kinetics Model

Paste Feed (g/min)	Monomer Circulation (g/min)	Temp. °C	Paste Mole Ratio (EG/PTA)	Unreacted PTA Weight %	Model predicted % Conversion	Measured % Conversion
19	507	261.5	1.8	2.93	90.935	86.500
15	507	261.5	1.8	3.34	90.228	85.490

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The specific embodiments described and shown in the specification and drawings should be taken as illustrative of the present invention and not for purposes of limiting the claims that follow, unless specifically indicated otherwise.

WHAT IS CLAIMED IS:

1. A process for making a pre-polyester comprising:
 - 5 providing an esterification pipe reactor comprising a pipe, the pipe having an inlet and an outlet and constructed such that flow inside the pipe from the inlet to the outlet follows a path that is not totally vertical nor totally horizontal; and
 - reacting one or more reactants flowing in the pipe towards the outlet under esterification reaction conditions to form the pre-polyester.
- 10 2. The process of claim 1 wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall upward, but not totally vertical path.
- 15 3. The process of claim 2 wherein the pipe is substantially empty.
4. The process of claim 2 wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall upward, but not totally vertical path, with this path being also generally non-downward, non-vertical.
- 20 5. The process of claim 4 wherein the pipe is substantially empty.
6. A process for making a polyester oligomer, a polyester or both comprising:
 - 25 performing the process according to claim 2, 3, 4 or 5 to make a pre-polyester; and
 - reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

7. The process of claim 6 wherein the step of reacting under polycondensation reaction conditions is carried out in a polycondensation pipe reactor.
8. The process of claim 2, 3, 4 or 5 further comprising removing vapor from inside
5 the pipe.
9. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 8 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under
10 polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.
10. The process of claim 2, 3, 4 or 5 wherein the pipe is serpentine.
11. The process of claim 2, 3, 4 or 5 further comprising adding a solubilizing agent
15 into the pipe.
12. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 11 to make a pre-polyester; and
20 reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.
13. The process of claim 11 wherein the solubilizing agent comprises a polyester
25 oligomer.
14. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 13 to make a pre-polyester; and

reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

5 15. The process of claim 2, 3, 4 or 5 wherein the reactants forming the pre-polyester comprise a diacid, a diol, a diester, a hydroxy ester, an acid ester, a hydroxy acid or combinations thereof.

10 16. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 15 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

15 17. The process of claim 2, 3, 4 or 5 wherein the reactants forming the pre-polyester comprise TPA, DMT, CHDM, IPA, EG or combinations thereof.

18. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 17 to make a pre-polyester; and
20 reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

25 19. The process of claim 2, 3, 4 or 5 further comprising adding a solubilizing agent comprising a polyester oligomer into the pipe and wherein the reactants forming the pre-polyester comprise TPA, DMT, CHDM, IPA, EG or combinations thereof.

30 20. The process of claim 8 further comprising adding a solubilizing agent comprising a polyester oligomer into the pipe and wherein the reactants forming the pre-polyester comprise TPA, DMT, CHDM, IPA, EG or combinations thereof.

21. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 19 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under
5 polycondensation reaction conditions, to form the polyester oligomer, the polyester
or both.
22. The process of claim 6 wherein the polyester is PET or PETG.
- 10 23. The process of claim 2, 3, 4 or 5 wherein stratified flow appears in the pipe.
24. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 23 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under
15 polycondensation reaction conditions, to form the polyester oligomer, the polyester
or both.
25. The process of claim 2, 3, 4 or 5 wherein the liquid superficial velocity is
between 0.01 and 0.15 m/s and the vapor superficial velocity is between 0.6 and 3.0
20 m/s across any full cross sectional area inside the pipe perpendicular to the flow
path in the pipe.
26. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 25 to make a pre-polyester; and
25 reacting the pre-polyester and optionally other reactants, under
polycondensation reaction conditions, to form the polyester oligomer, the polyester
or both.
27. The process of claim 2, 3, 4 or 5 wherein B_x is less than 4.0 while B_y is less than
30 2.0 or B_x is greater than or equal to 4.0 while $(\log_{10} B_y)$ is less than or equal to -

$0.677(\log_{10} B_x) + 0.700$ on average across any full cross sectional area inside the pipe perpendicular to the flow path in the pipe.

28. A process for making a polyester oligomer, a polyester or both comprising:

- 5 performing the process according to claim 27 to make a pre-polyester; and
 reacting the pre-polyester and optionally other reactants, under
polycondensation reaction conditions, to form the polyester oligomer, the polyester
or both.

10 29. The process of claim 19 wherein stratified flow appears in the pipe.

30. A process for making a polyester oligomer, a polyester or both comprising:

- performing the process according to claim 29 to make a pre-polyester; and
 reacting the pre-polyester and optionally other reactants, under
15 polycondensation reaction conditions, to form the polyester oligomer, the polyester
or both.

31. The process of claim 17 wherein the pipe is serpentine and stratified flow
appears in the pipe.

20

32. The process of claim 20 wherein the pipe is serpentine and stratified flow
appears in the pipe.

33. The process of claim 19 wherein the pipe is serpentine and stratified flow
25 appears in the pipe.

34. The process of claim 33 wherein the step of reacting under polycondensation
reaction conditions is carried out in a polycondensation pipe reactor.

35. The process of claim 21 wherein the pipe is serpentine and stratified flow appears in the pipe, the step of reacting under polycondensation reaction conditions is carried out in a polycondensation pipe reactor and the polyester is PET.

5 36. The process of claim 1 wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall downward, but not totally vertical path.

37. The process of claim 36 wherein the pipe is substantially empty.

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38. The process of claim 36 wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall downward, but not totally vertical path, with this path being also generally non-upward, non-vertical.

15 39. The process of claim 38 wherein the pipe is substantially empty.

40. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 36 or 37 to make a pre-polyester;
and

20 reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

41. The process of claim 40 wherein the step of reacting under polycondensation
25 reaction conditions is carried out in a polycondensation pipe reactor.

42. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 38 or 39 to make a pre-polyester;
30 and

reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

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43. The process of claim 42 wherein the step of reacting under polycondensation reaction conditions is carried out in a polycondensation pipe reactor.

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44. The process of claim 36, 37, 38 or 39 further comprising removing vapor from inside the pipe.

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45. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 44 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

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46. The process of claim 36, 37, 38 or 39 further comprising removing vapor from the pipe at a least one bend and wherein the pipe is serpentine and has at least one weir at an effective distance from a bend.

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47. The process of claim 36, 37, 38 or 39 further comprising adding a solubilizing agent into the pipe.

48. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 47 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

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49. The process of claim 47 wherein the solubilizing agent comprises a polyester oligomer.

50. A process for making a polyester oligomer, a polyester or both comprising:

- 5 performing the process according to claim 49 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

10 51. The process of claim 36, 37, 38 or 39 wherein the reactants forming the pre-polyester comprise a diacid, a diol, a diester, a hydroxy ester, an acid ester, a hydroxy acid or combinations thereof.

52. A process for making a polyester oligomer, a polyester or both comprising:

- 15 performing the process according to claim 51 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

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53. The process of claim 36, 37, 38 or 39 wherein the reactants forming the pre-polyester comprise TPA, DMT, CHDM, IPA, EG or combinations thereof.

54. A process for making a polyester oligomer, a polyester or both comprising:

- 25 performing the process according to claim 53 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

55. The process of claim 36, 37, 38, 39 or 44 further comprising adding a solubilizing agent comprising a polyester oligomer into the pipe and wherein the reactants forming the pre-polyester comprise TPA, DMT, CHDM, IPA, EG or combinations thereof.

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56. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 55 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under
polycondensation reaction conditions, to form the polyester oligomer, the polyester
or both.

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57. The process of claim 40, 41, 42, or 43 wherein the polyester is PET or PETG.

58. The process of claim 36, 37, 38 or 39 wherein stratified flow appears in the
pipe.

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59. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 55 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under
polycondensation reaction conditions, to form the polyester oligomer, the polyester
or both.

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60. The process of claim 36, 37, 38 or 39 wherein the liquid superficial velocity is
between 0.01 and 0.15 m/s and the vapor superficial velocity is between 0.6 and 3.0
m/s across any full cross sectional area inside the pipe perpendicular to the flow
path in the pipe.

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61. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 60 to make a pre-polyester; and

reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.

- 5 62. The process of claim 36, 37, 38 or 39 wherein B_x is less than 4.0 while B_y is less than 2.0 or B_x is greater than or equal to 4.0 while $(\log_{10} B_y)$ is less than or equal to $-0.677(\log_{10} B_x) + 0.700$ on average across any full cross sectional area inside the pipe perpendicular to the flow path in the pipe.
- 10 63. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 62 to make a pre-polyester; and
reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.
- 15 64. The process of claim 55 wherein stratified flow appears in the pipe.
65. A process for making a polyester oligomer, a polyester or both comprising:
performing the process according to claim 64 to make a pre-polyester; and
20 reacting the pre-polyester and optionally other reactants, under polycondensation reaction conditions, to form the polyester oligomer, the polyester or both.
- 25 66. The process of claim 54 or 55 wherein the pipe is serpentine and stratified flow appears in the pipe.
67. The process of claim 66 wherein the step of reacting under polycondensation reaction conditions is carried out in a polycondensation pipe reactor.

68. The process of claim 56 wherein the pipe is serpentine and stratified flow appears in the pipe, the step of reacting under polycondensation reaction conditions is carried out in a polycondensation pipe reactor and the polyester is PET.

5 69. An apparatus for making a pre-polyester comprising:

an esterification pipe reactor comprising a pipe, the pipe having an inlet and an outlet and constructed such that flow inside the pipe from the inlet to the outlet follows a path that is not totally vertical nor totally horizontal; and

wherein pre-polyester forming reactants are passed towards the outlet.

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70. The apparatus of claim 69 wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall upward, but not totally vertical path.

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71. The apparatus of claim 70 wherein the pipe is substantially empty.

72. The apparatus of claim 70 wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall upward, but not totally vertical path, with this path being also generally non-downward, non-vertical.

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73. The apparatus of claim 72 wherein the pipe is substantially empty.

74. An apparatus for making a polyester oligomer, a polyester or both comprising:
the apparatus of claim 70; and

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a polycondensation reactor connected to the outlet of the pipe.

75. The apparatus of claim 74 wherein the polycondensation reactor is a polycondensation pipe reactor.

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76. An apparatus for making a polyester oligomer, a polyester or both comprising:

the apparatus of claim 71; and
a polycondensation reactor connected to the outlet of the pipe.

5 77. The apparatus of claim 76 wherein the polycondensation reactor is a polycondensation pipe reactor.

78. An apparatus for making a polyester oligomer, a polyester or both comprising:
the apparatus of claim 72; and
a polycondensation reactor connected to the outlet of the pipe.

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79. The apparatus of claim 78 wherein the polycondensation reactor is a polycondensation pipe reactor.

15 80. An apparatus for making a polyester oligomer, a polyester or both comprising:
the apparatus of claim 73; and
a polycondensation reactor connected to the outlet of the pipe.

81. The apparatus of claim 80 wherein the polycondensation reactor is a polycondensation pipe reactor.

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82. The apparatus of claim 72 further comprising means for removing vapor from inside the pipe at at least one point along the pipe.

25 83. The apparatus of claim 73 further comprising means for removing vapor from inside the pipe at at least one point along the pipe.

84. The apparatus of claim 70 wherein the pipe is serpentine.

30 85. The apparatus of claim 72 further comprising a tank for holding solubilizing agent connected to the pipe at a point other than the outlet.

86. The apparatus of claim 72 further comprising a recycle line connecting the pipe at a point nearer to the outlet than the inlet with the pipe at a point nearer the inlet than the outlet.

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87. The apparatus of claim 78 further comprising a flow line from the polycondensation reactor to the pipe at a point other than the outlet.

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88. The apparatus of claim 69 wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall downward, but not totally vertical path.

89. The apparatus of claim 88 wherein the pipe is substantially empty.

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90. The apparatus of claim 88 wherein the pipe is constructed such that flow inside the pipe from the inlet to the outlet follows an overall downward, but not totally vertical path, with this path being also generally non-upward, non-vertical.

91. The apparatus of claim 90 wherein the pipe is substantially empty.

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92. An apparatus for making a polyester oligomer, a polyester or both comprising:
the apparatus of claim 88; and
a polycondensation reactor connected to the outlet of the pipe.

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93. The apparatus of claim 92 wherein the polycondensation reactor is a polycondensation pipe reactor.

94. An apparatus for making a polyester oligomer, a polyester or both comprising:
the apparatus of claim 89; and

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a polycondensation reactor connected to the outlet of the pipe.

95. The apparatus of claim 94 wherein the polycondensation reactor is a polycondensation pipe reactor.
- 5 96. An apparatus for making a polyester oligomer, a polyester or both comprising:
the apparatus of claim 90; and
a polycondensation reactor connected to the outlet of the pipe.
- 10 97. The apparatus of claim 96 wherein the polycondensation reactor is a polycondensation pipe reactor.
- 15 98. An apparatus for making a polyester oligomer, a polyester or both comprising:
the apparatus of claim 91; and
a polycondensation reactor connected to the outlet of the pipe.
- 20 99. The apparatus of claim 98 wherein the polycondensation reactor is a polycondensation pipe reactor.
- 20 100. The apparatus of claim 90 further comprising means for removing vapor from inside the pipe at at least one point along the pipe.
- 25 101. The apparatus of claim 91 further comprising means for removing vapor from inside the pipe at at least one point along the pipe.
- 25 102. The apparatus of claim 88 further comprising means for removing vapor from the pipe at a least one bend and wherein the pipe is serpentine and has at least one weir at an effective distance from a bend.

103. The apparatus of claim 89 further comprising removing vapor from the pipe at a least one bend and wherein the pipe is serpentine and has at least one weir at an effective distance from a bend.

5 104. The apparatus of claim 90 further comprising removing vapor from the pipe at a least one bend and wherein the pipe is serpentine and has at least one weir at an effective distance from a bend.

105. The apparatus of claim 90 further comprising a tank for holding solubilizing agent connected to the pipe at a point other than the outlet.
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106. The apparatus of claim 90 further comprising a recycle line connecting the pipe at a point nearer to the outlet than the inlet with the pipe at a point nearer the inlet than the outlet.

15 107. The apparatus of claim 96 further comprising a flow line from the polycondensation reactor to the pipe at a point other than the outlet.

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