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SOLVENT RECOVERY AND DISPOSAL OF UNRECOVERABLE SOLVENTS USED IN THE PHARMACEUTICAL INDUSTRY

<u>Sectoral Working Paper Series</u>

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22

SECTORAL WORKING PAPERS

In the course of the work on major sectoral studies carried out by UNIDO, Studies and Research, several working papers are produced by the secretariat and by outside experts. Selected papers that are believed to be of interest to a wider audience are presented in the Sectoral Working Papers series. These papers are more exploratory and tentative than the sectoral studies. They are therefore subject to revision and modification before being incorporated into the sectoral studies.

Preface

The main objectives of this study are: first, a technical analysis of solvent recovery operations in the pharmaceutical industry; secondly, to the extent that data are available, an analysis of the economics of solvent recovery. The examples are drawn from the experiences in developed countries because there was the information obtainable. But aspects of solvent recovery which are especially important for developing countries are pointed out throughout the study.

Recovery of waste solvents from chemical processes is good policy for protecting the environment and a sensible business policy in view of the high prices of solvents and their shortages in some developing countries. Good practice in design and operation of pharmaceutical manufacturing plants will mean that solvents will be recovered from vapours as well as from liquid mixtures in reaction vessels. The major problem is the recovery of solvents in sufficient purity for re-use in process operations. That will be a major concern of this study. Another concern is recovery of solvents for vessel cleaning and other housekeeping issues.

The great limitation in carrying out the present study was the lack of published data in solvent recovery in the pharmaceutical industry. The data were received to a large extent through the co-operation of the Janssen Pharmaceutical Company, the Chinoin Pharmaceutical and Chemical Works Ltd., and the Gedeon Richter Pharmaceutical Company. The co-operation of Mr. Barna Mezey, Ministry of Industries, Hungary, is especially acknowledged. He organized and was a valuable contributor to all the meetings with the Hungarian pharmaceutical and engineering design firms.

The study will serve as a background document to the Third Consultation on the Pharmaceutical Industry, Madrid, April 1987. This is the third in a series of environmental research studies on the pharmaceutical industry prepared by UNIDO, Studies and Research Division. The present study was inspired by preliminary work which formed a part of the second study "Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list" presented to the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983.

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Glossary of terms

Batch rectification: Batch multiple single distillation from a distillation tower or, equivalently, fractional distillation.

BOD_5 or BOD: Biochemical oxygen demand. The 5-day, 20°C, BOD_5 test is widely used to determine the pollutional strength of waste water in terms of the oxygen required to oxidize or convert the organic matter to a nonputrescible end product. The BOD_5 test is a bioassay procedure that measures the oxygen consumed by living organisms while utilizing the organic matter present in the waste water under conditions as similar as possible to those that occur in nature.

COD: Chemical oxygen demand. The COD test is an alternative to the BOD_5 test. It is widely used and measures the quantity of oxygen required to oxidize the materials in waste water under severe chemical and physical conditions. The major advantage of the COD test is that only a short period (three hours) is required to conduct the test. The major disadvantage is that the test does not indicate how rapidly the biologically active materials would be stabilized in natural conditions.

Continuous rectification: Continuous distillation from a distillation tower.

Isopleth: A graph showing the frequency of occurrence of any phenomenon as a function of two variables, generally used with reference to meteorological elements.

MLSS: In the treatment of waste water by the activated sludge process, the activated sludge together with the raw waste water is called mixed liquor, and the sludge soils in the system are known as mixed liquor suspended solids (MLSS).

Overhead stripping (from a batch reactor): Simple batch distillation.

Salting: A process in which solvent is passed through a bed of anhydrous salt, such as calcium chloride, in order to remove the water.

Solvent recovery: Used synonymously with solvent reclamation or solvent recuperation.

Used, or waste, solvents: Organic dissolving agents which are contaminated with suspended and/or dissolved inorganic solids, organic materials, water, other solvents, or any other foreign matter not present in the purchased, or virgin, solvent.

EXPLANATORY NOTES

References to dollars ($) are to United States dollars, unless otherwise stated.

A comma (,) is used to distinguish thousands and millions.

A full stop (.) is used to indicate decimals.

A slash between dates (e.g., 1980/81) indicates a crop year, financial year or academic year.

Use of a hyphen between dates (e.g., 1960-1965) indicates the full period involved, including the beginning and end years.

Metric tons have been used throughout.

The following forms have been used in tables:

Three dots (...) indicate that data are not available or are not separately reported.

A dash (-) indicates that the amount is nil or negligible.

A blank indicates that the item is not applicable.

Totals may not add up precisely because of rounding.

1. INTRODUCTION

The pharmaceuticals industry is unique among industrial sectors because of the variety of solvents which are used. For example, the Janssen Pharmaceutical Company used a total of 26 different organic solvents in process operations in 1984.

Organic solvents are used by the pharmaceuticals industry as chemical media for reactions, extractions, for equipment cleaning and for other cleaning purposes. To meet the variety of industrial needs, solvents such as halogenated, aliphatic and aromatic hydrocarbons, alcohols, esters, glycol ethers and ketones are required. Some specific examples include methyl ethyl ketone, benzene, dichloromethane and isopropanol.[1/]

In general, pharmaceutical plants in the developed countries make a concerted effort to recover their used solvents whenever this is economically feasible. Recovery usually makes good sense, economically and environmentally.

In developing countries the economics of solvent recovery may be especially favourable because scarce hard currency can thereby be saved. Lower imports of virgin solvent mean lower expenditures of foreign exchange.

Used or waste solvents are defined as organic dissolving agents which are contaminated with suspended and/or dissolved inorganic solids, organic materials, water, other solvents, and/or any substance not present in the virgin solvent. Reclaiming is the process of restoring a waste solvent to a condition that permits its reuse. Reclaiming is carried out by removing materials that have contaminated the solvent during industrial use. From a technological standpoint any solvent can be reclaimed to a point where it can be reused, either for an alternative use or its original purpose. The limiting factor determining whether a solvent is to be reclaimed is economic.[2/] Sometimes even if the reclaiming is technically feasible,

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[1/] United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratory, Cincinnati, Ohio, USA, April 1978, p. 1.

[2/] Pollution Probe Foundation. Profit from Pollution Prevention, A Guide to Industrial Waste Reduction and Recycling. Washington, DC, USA (undated), p. 239.

the cost of reclaiming certain waste solvents may be higher than the cost of the virgin material.

A solvent which is not consumed during one of the chemical reactions en route to making a pharmaceutical product will usually become contaminated and, therefore, will be unacceptable for further use unless purified, or reclaimed. If used solvents are reclaimed, they can be reused for their original purpose or for other industrial needs. The reclaiming of waste solvents has become important due to the rising cost of virgin solvents and the cost of waste solvent disposal. These economic incentives as well as environmental laws which do not permit discharge of waste solvents have encouraged pharmaceutical companies to recover their solvents for reuse.

Solvent recovery units for pharmaceutical firms fall under four categories: (1) stripping, (2) distillation towers, (3) product drying under vacuum or atmospheric pressure, (4) use of activated carbon. All are discussed in the study, though the first two are most commonly used.

In the pharmaceutical industry, purification of a single solvent present in a reactor vessel is usually carried out by overhead stripping. Purification of solvent mixtures is usually accomplished by rectification. In the case of complex mixtures one may require some combination of liquid-liquid extraction and decanting followed by rectification.[3/,4/,5/]

The distillation tower is the most common process for recovery of solvents in the pharmaceutical industry. Such a distillation tower typically consists of a vertical sequence of stages for contacting liquid and vapor. In the rectification section heavier components are condensed into a decending liquid phase from a countercurrent ascending vapor phase, thereby enriching or purifying the vapor which is itself condensed at the top of the column. A portion of the condensed vapor is returned as reflux to the column while the

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3/ Chinoin Pharmaceutical and Chemical Works, Ltd. Budapest, Hungary. Unpublished data, 1986.

4/ Gedeon Richter Pharmaceutical Company, Budapest, Hungary. Unpublished data, 1986.

5/ Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

balance is withdrawn as overhead product. In the bottom section the descending liquid gives up lighter components to rising vapors. The liquid which is removed from the bottom of the column therefore contains the heavier components.

In the pharmaceutical industry, companies are working generally with batch processes. The reaction typically takes place in some solvent or solvent mixture. The products are separated from the solvent. In the simplest case, the solvent will be stripped from the product in the reaction vessel, either at atmospheric pressure or under vacuum. The solvent recovered in this case, if not contaminated, will be reutilized in the production process. However, this is unusual. For example, even the water produced in the reaction can contaminate the solvent. The solvent contaminated with water is purified by passing through the distillation tower or a bed of an anhydrous salt. Only those solvents will be passed through the distillation tower which have already been at least partially purified by stripping.[6/]

Hydrocarbon and particulate emissions result from the reclaiming of waste solvents. Emission points from plants reclaiming waste solvents are storage tank vents, condenser vents, incinerator stacks, and fugitive losses.

Control equipment for hydrocarbon emissions during solvent recovery includes floating roofs, refrigeration, conservation vents for storage tanks, packed scrubbers, and secondary condensers for distillation units. In the case of incineration of waste solvents control of particulates from incinerator stacks is accomplished with wet scrubbers.[7/]

Fugitive emissions are a major source of emissions, comprising at least 20 per cent of the total hydrocarbon air emissions during industrial solvent recovery operations in the United States.[8/] Control of fugitive emissions

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6/ Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

7/ United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratory, Cincinnati, Ohio, USA, April 1978, p. 8.

8/ *Ibid*, p. 9.

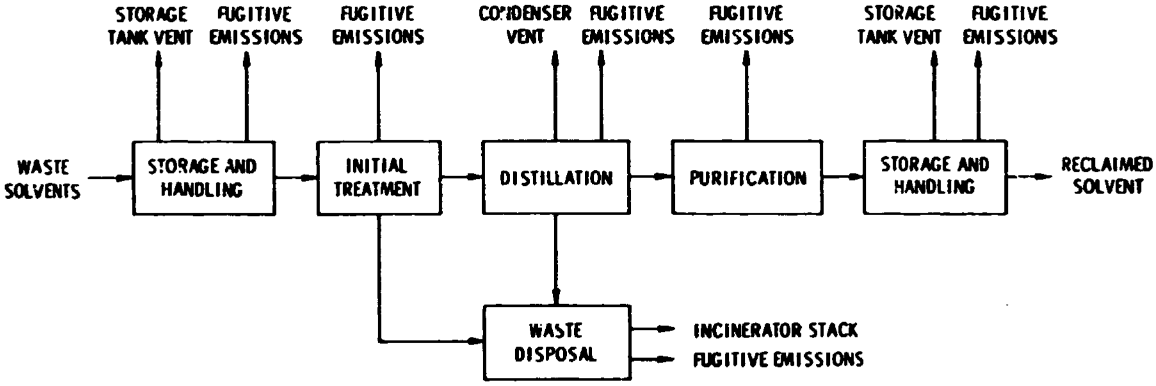
is accomplished by proper plant maintenance, by improved loading procedures such as submerged filling and by reducing the number of solvent sources open to the atmosphere.

The general solvent reclaiming process is depicted by the unit operations in Figure 1, General Scheme for Solvent Recovery.[9/] Methods employed in each unit operation and criteria for their utilization are described in the later sections of the study.

Case studies drawn from pharmaceutical operations in several countries, especially Belgium or Hungary, are presented to provide practical illustrations of the general principles discussed.

[9/] Ibid, p. 7.

Figure 1. General scheme for solvent recovery



Source: United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Research Laboratory, Cincinnati, Ohio, USA, April 1978, p. 7.

2. PROCESS DESCRIPTIONS FOR SOLVENT RECOVERY

2.1 Solvent storage and handling

Waste solvents are stored before and after reclamation. This may take place on the site of the pharmaceutical plant. The solvents may be transported in pipelines, tank cars and drums, to the reclaiming plant at a different site where they are recovered and then returned to the initial site. This procedure involves continuous storage and handling since solvent must be loaded on and off tank cars and trucks and stored until processing time is available. An example is the Gedeon Richter plant in Hungary, where some waste solvents from the Budapest plant are shipped to the Dorok plant for reclamation.[10/]

Solvents are stored in containers ranging in size from approximately 200 l drums to tanks with capacities of 75 m^3 or more. Storage tanks are of fixed or floating roof design. Fixed-roof tanks are metal cylinders or boxes of rigid construction. Venting systems are used to prevent solvent vapors from creating excessive pressure inside the tanks. Floating-roof tanks have movable tops which float on the surface of the contained solvent while forming an airtight seal with the tank walls.

The handling of used and recovered solvents includes the filling of drums and tanks prior to transport and storage and the loading of recovered solvent into process equipment. Filling of tanks and drums is done through splash or subsurface loading. Splash loading is the filling of the tank or drum from the top, allowing solvent to fall free to the bottom of the container. Subsurface filling is accomplished by pumping the solvent into the bottom of the solvent container.[11/]

10/ Gedeon Richter Pharmaceutical Company, Budapest, Hungary. Unpublished data, 1986.

11/ United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratory, Cincinnati, Ohio, USA, April 1978, p. 8.

In tropical climates, storage tanks may need to be built underground. Drums, if kept in the open, may need to be sprayed continuously with water. Drums should not be filled full of solvent because the solvent will expand with an increase in temperature, possibly rupturing the drum. All of the above precautions may be necessary to eliminate explosion hazards.

2.2 Initial treatment by mechanical separation

Undissolved solids and water are removed from liquid waste solvents by initial treatment through mechanical separation. This means of separating water from solvent is feasible if the solvent is immiscible in water. Methods for mechanical separation include decanting, filtering, draining, settling, and use of a centrifuge. Decanting is used to separate water from immiscible solvent, while the other methods are used to remove undissolved solids from the waste solvent. A simple cone tank used for settling out solids from waste solvent is shown in Figure 2.[12/]

A combination of initial mechanical treatment methods may be necessary to prepare a waste solvent for further processing. For example, a contaminated liquid solvent may be filtered to remove undissolved solids and then decanted to remove water before distillation. Distillation is not necessary if the recovered solvent or solvent mixtures can be reused without separation.

2.3 Distillation

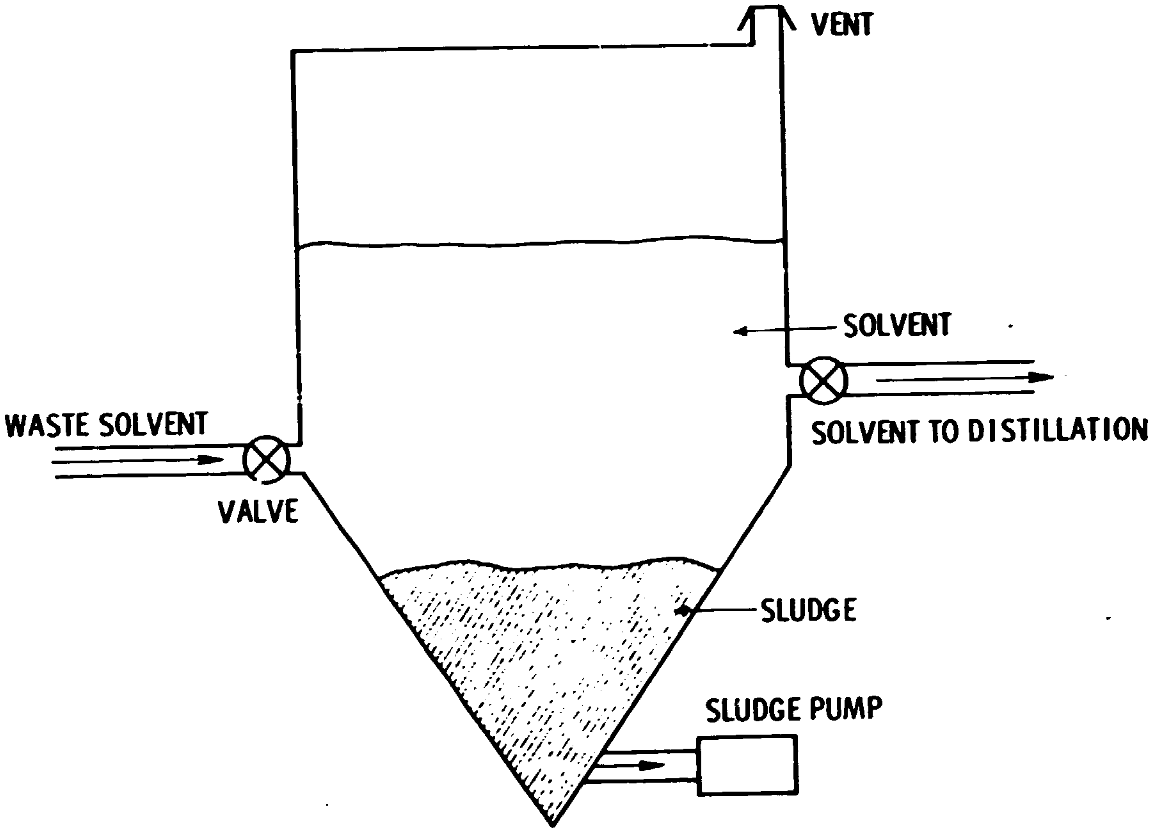
After initial treatment as necessary, waste solvents are distilled to separate solvent mixtures and to remove dissolved impurities. Details of the distillation unit operation are shown in Figure 3.[13/] Waste solvents are distilled by one of the three distillation methods listed below:[14/]

[12/] *Ibid*, p. 11.

[13/] *Ibid*, p. 12.

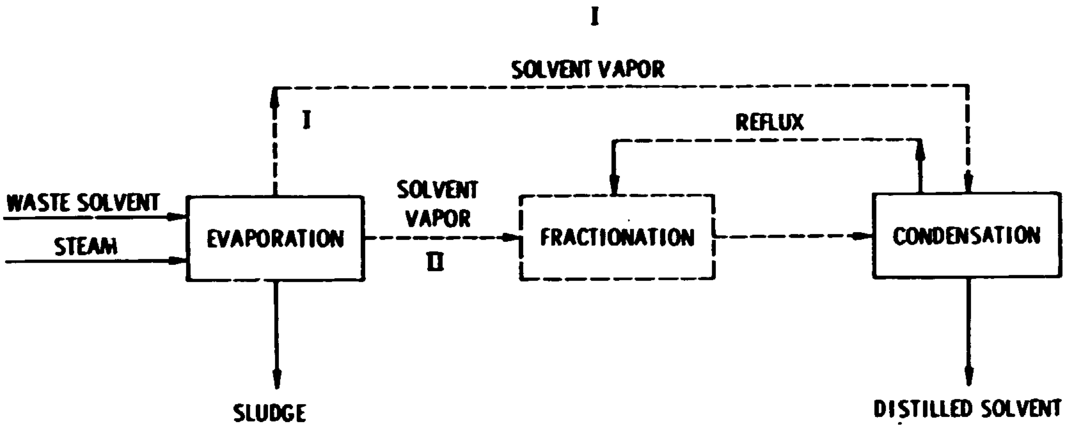
[14/] Vegyterv Engineering Company. Budapest, Hungary. Unpublished data, 1986.

Figure 2. Cone settling tank for removal of undissolved solids from waste solvent



Source: United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratory, Cincinnati, Ohio, USA, April 1978, p. 11.

Figure 3. Distillation process for solvent reclaiming



Source: United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratories, Cincinnati, Ohio, USA, April 1978, p. 12.

- Simple batch distillation
- Batch rectification
- Continuous rectification

Simple batch distillation

In simple batch distillation a quantity of waste solvent is present in the batch reactor, whereas pharmaceutical products or intermediates have been produced through reaction in the solvent. After steam heating the reactor, solvent vapors are continuously removed and condensed. The resulting sludge or still bottom is removed from the reactor after solvent evaporation. Distillation follows path I or the distillation process shown in Figure 3. The method is frequently sufficient for separating solvents from their dissolved contaminants.

Batch rectification

In pharmaceutical plants, solvents are recovered whenever possible by simple stripping of the solvent overhead from the reaction vessel. Where it is impossible to recover the solvent in this fashion or where the solvent is not recovered in sufficient purity, the contaminated solvents are sent to distillation towers. At the Janssen pharmaceutical plant, for example, there are two such towers of 10,000 liters capacity with steam heated jackets.15/ In order to maximize the recovery of solvents through stripping in the production units, a skilled operator is especially important. This is due to variations in solvents used and solvent impurities from day to day. The operator may require specialized courses in industrial chemistry and engineering as well as thorough on the job training.

The Chinoin Pharmaceutical Company is divided into four plant groups: one for production, one for synthesis, one for fermentation and one for preparations (dosage forms). Simple stripping occurs in each of the

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15/ Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

production activities within a plant group. More complex separations take place in a central unit which operates the distillation towers.[16/]

Within production activities and the central distillation unit solvents are recovered in high purity for reuse in process equipment. However, many solvents of slightly less purity are recovered for use in cleaning equipment and general maintenance or are sold.

Table 1 shows the amounts of solvents used in chemical production and solvent recovery at the Janssen Pharmaceuticals Plant.[17/] Janssen uses a total of 31 solvents, including a wide variety of organic solvents and two inorganic solvents. They use nearly 2.2 million liters of solvent annually and another 220,000 liters for equipment cleaning and other general purposes. Nearly one million liters of solvent are recovered annually, either by overhead stripping (simple batch distillation) or by batch rectification in one of the distillation towers. Table 1 includes recovery of 11,990 liters of methylisobutylketone/toluene mixtures. However, figures on the quantities of mixtures of these solvents used in production were not available.

Table 2 shows the quantities of solvents used and recovered by the Chinoin Pharmaceutical and Chemical Works Ltd., Hungary, in 1983.[18/] 13 organic solvents were used in substantial quantities. The overall recovery experience is remarkably similar to that at Janssen. About 18 million liters of solvents were consumed and of these, 9.3 million - or about half - were recovered.

The Gedeon Richter Pharmaceutical Company also recovers overall about half of its purchases of about 25.5 tons of 17 organic solvents. The figures are shown in Table 3.[19/]

[16/] Chinoin Pharmaceutical and Chemical Works, Ltd., Budapest, Hungary. Unpublished data, 1986.

[17/] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

[18/] Chinoin Pharmaceutical and Chemical Works, Ltd., Budapest, Hungary. Unpublished data, 1986.

[19/] Gedeon Richter Pharmaceutical Company, Budapest, Hungary. Unpublished data, 1986.

Table 1 : Amounts of solvents used in chemical production and their recovery yields (in liters), Janssen Pharmaceutical Company

Solvent	Use of solvents			Solvents recovered		
	Production	General (cleaning, etc.)	Total	Total	From production (%)	From general use (%)
Acetone, cp	145.930	94,404	240,334	85,316	58	34
Chloroform	73.669	21,680	95,349	57,475	78	60
1,2-dichloroethane	202,585	2,500	205,085	35,560	18	17
n,n-dimethylacetamide	6,868	96	6,964			
Dimethylformamide	74,162	1,356	75,518	400	1	1
Ethylacetate	64,322	70	64,392	36,560	57	57
Ethanol abs, denatured	140,560	3,450	144,010	22.237	16	15
2-propanol	250,471	5,310	255,781	170.038	68	66
Methanol	358,109	7,370	365,479	82,598	23	23
Dichloromethane	16,916	700	17,616	8,740	52	50
4-methyl-2-pentanone	103,798	1,500	105,298	83,130	76	75
Tetrahydrofuran	65,744	100	65,844	29,600	45	45
Toluene	314,923	19,347	334,270	262,435	83	79
Dimethylbenzene	45,682	2,300	47,982	32,580	71	68
Tetrahydrofuran, distilled	4,000	240	4,240			
Benzene	6,927		6,927			
1-butanol	2,118		2,118			
Chlorobenzene	50,155		50,155	41,084	82	82
Cyclohexanol	1,722		1,722	200	12	12
1,2-dichlorobenzene	6,831		6,831	4,840	71	71
Ethanol, denatured	2,150		2,150	2,150	100	100
Ethylbenzene	70		70			
Fluorobenzene	1,523		1,523			
2-Butanone	23,495		23,495	15,879	68	68
1,1,2,2-tetrachloroethylene	846		846	749	88	88
Heptane, 50%	2,885		2,885			
Methylisobutylketone/ toluene mixtures				11,990		
TOTAL	1,966,461	160,423	2,126,884	983,471	45	41

Notes: cp = chemically pure, abs = absolute; a small amount of ammonia is also recovered.
Source: Janssen Pharmaceutica, Beerse, Belgium, October 1985.

Table 2. Solvents used and recovered in 1983 (in liters),[a] Chinoin Pharmaceutical and Chemical Works Ltd.

Solvent	Consumption			Reusable
	Total	Purchased	Recovered/ purified	
Acetone	7,967,176	3,631,770	4,335,410	4,335,410
Benzene	562,626	485,486	77,141	86,727
1,2 Dichloroethane	882,742	140,087	742,655	742,655
Dichloromethane	42,948	39,592	3,310	1,666
Dimethylformamide	304,502	304,502	-	-
Ethylacetate	92,388	43,954	48,434	53,476
Ethanol	1,904,929	1,464,414	440,515	1,108,595
Isopropylalcohol	111,779	102,996	8,784	14,235
Chloroform	173,207	163,632	9,574	14,751
Methanol	9,905,952	5,312,281	4,593,672	4,593,672
Methylethylketone	832,885	225,398	607,486	605,885
Toluene	957,336	203,604	753,731	782,570
Xylene	55,624	53,552	2,072	2,072
TOTAL	23,794,094	12,171,268	11,622,784	12,341,714

[a] Volumes in liters were calculated from kilograms using densities obtained from the Handbook of Chemistry and Physics, 51st Edition. Physical Constants of Organic Compounds Table. The Chemical Rubber Company, Cleveland, Ohio, USA, 1971.

Source: Chinoin Pharmaceutical and Chemical Works Ltd., Budapest, January 1986.

Table 3. Purchases and recoveries of solvents, Gedeon Richter Pharmaceutical Company, 1985 (in liters)a/

Solvent	Purchases of pure solvent liters/year	Contaminated solvent for recovery liters/year	Recovered solvent liters/year	Amount of lost solvent liters/year	Percentage
Acetone	1,025,000	506,000	405,000	101,000	20
Benzene	3,073,000	1,929,000	1,582,000	347,000	18
n-Butanol	308,000	621,000	456,000	164,000	26.4
Diethylene glycol	803,000	-	-	-	-
1,2-Dichloroethane	340,000	2,137,000	1,943,000	194,000	9
Dichloromethane	256,000	196,000	151,000	45,000	23
Dimethylformamide	1,582,000	-	-	-	-
Ethyl acetate	944,000	1,110,000	888,000	222,000	20
Ethanol	2,913,000	1,474,000	1,228,000	245,000	16.6
Ethylene glycol	450,000	-	-	-	-
Chlorobenzene	144,000	114,000	99,000	14,000	12.7
Isopropanol	534,000	381,000	330,000	50,000	13.3
Chloroform	984,000	1,348,000	1,146,000	202,000	15
Methanol	14,847,000	4,498,000	3,664,000	833,000	18.5
Tetrahydrofuran	247,000	176,000	154,000	22,000	12.7
Toluene	911,000	1,707,000	1,361,000	346,000	20.2
Xylene	126,000	-	-	-	-
TOTAL	28,667,000	15,638,000	13,407,000	2,785,000	

Source: Gedeon Richter Pharmaceutical Company, Budapest, Hungary, January 1986

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a/ Volumes in liters were calculated from kilograms using densities obtained from the Handbook of Chemistry and Physics, 51st Edition. Physical Constants of Organic Compounds Table. The Chemical Rubber Company, Cleveland, Ohio, USA, 1971.

In Table 4 is shown the recuperation by rectification of the eight high volume solvents in use at Janssen Pharmaceutical Company.[20/] There is very little variation in the yield of recovered solvent. Between 70 per cent and 85 per cent of the incoming amounts of waste solvents are recovered as pure solvent.

The separation of mixed solvents requires multiple simple distillations or rectification. Batch and continuous rectification are represented by path II in Figure 5. In batch rectification, solvent vapors pass through a distillation column where they contact condensed solvent (reflux) entering at the top of the column. Solvent not returned as reflux is drawn off as overhead product. In continuous rectification, the waste solvent feed enters continuously at an intermediate point in the column. The more volatile solvents are drawn off at the top of the column while higher boiling point solvents collect at the bottom.

Continuous rectification

The distillation tower is presently the most common process for recovery of solvents in the pharmaceutical industry. Conditions for continuous rectification are as follows:

Continuous rectification: 100-200 liters/hour distilled over a time period ranging from 100 to 1,000 hours.[21/]

Recovered solvents from the distillation tower are generally technically equivalent to pure solvents purchased outside. At Chinoin Pharmaceutical Company, the internal price is 75 per cent of the purchased price to encourage plants to use the recuperated solvents. A second inside price is the price of

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[20/] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

[21/] Vegyterv Engineering Company, Budapest, Hungary. Unpublished data, 1986.

Table 4: Solvent recuperation from the distillation tower (1984) at the Janssen Pharmaceutical Company (in liters)

Solvent	Incoming amount	Recuperated amount	Yield[a/] (per cent)
Chloroform	59,819	49,650	83
Dichloromethane	105,747	92,000	87
Dimethylbenzene	42,529	36,150	85
Ethylacetate	26,571	18,600	70
Methanol	17,674	15,200	86
Methylisobutylketone	119,667	89,750	75
Tetrahydrofuran	35,068	25,600	73
Toluene	235,244	192,900	82
Total	642,319	519,850	81

a/ The yield is expressed not as the efficiency of the distillation process but as the percentage of solvent recovered from the incoming waste solvent mixture.

Source: Janssen Pharmaceutica, Beerse, Belgium, October 1985.

contaminated solvent which the plant sends for recovery (15-20 per cent of the purchase price).[22/]

Binary single-phase azeotropes[23/]

Azeotropic behavior can be modified by changing the pressure or the number of components present, and both these techniques can be used in practice to shift or to eliminate an azeotrope in order to purify the components. For example, when methylethyl ketone (MEK) and water are distilled at one atmosphere an azeotrope is formed which contains 35 per cent water. If this azeotropic product is then distilled in a second column operated at 6.80 atmospheres the azeotrope is shifted to 50 per cent water and dry MEK can be produced at 6.80 atmospheres (absolute) from a 35 per cent water feed while the high-pressure azeotrope (50 per cent water) is recycled from the high pressure column back into the feed to the atmospheric column.

Azeotropic distillation refers to the method of adding a third component to the binary mixture to form a ternary azeotrope that separates into two layers. The layer enriched in the third component (called an entrainer) is totally refluxed. The other layer is enriched in one of the binary components and is mixed with the feed whereas the other binary component can be taken from the bottom of the column. The entrainer must be readily distillable from this bottom product. An example is the use of benzene as an entrainer for the azeotropic distillation of water-ethanol mixtures.

Sometimes extraction precedes the distillation. This is called extractive distillation. For example, an azeotrope can often be separated by first extracting one of the components into an immiscible solvent which does not form an azeotrope with either feed component. The two resulting phases can then be purified by separate distillations. The solvent is added to the distillation column to alter the relative volatility of the original pair allowing one component to distill overhead. The solvent leaves the column as

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22/ Chinoin Pharmaceutical and Chemical Works, Ltd., Budapest, Hungary. Unpublished data, 1986.

23/ Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387).

a bottom product with the other component and this mixture is then separated in a second column. Some examples are: acetone-methanol (water solvent), ethanol-water (ethylene glycol solvent), tetrahydrofuran-water (dimethylformamide solvent) and methanol-methylene chloride (water solvent).

Another example is the addition of phenol to cyclohexane-benzene mixtures during distillation which causes the activity coefficients for cyclohexane to be nearly twice as large as those for benzene. This factor causes the volatility of cyclohexane to be nearly twice that of benzene, allowing for their separation by distillation.[24/]

Still another method is to separate an azeotrope by extraction of one of its component into a solvent in which one component is miscible and the other immiscible. The two resulting phases can then be purified by separate distillations. An example is separation of a methanol-methylene chloride azeotrope by extracting the former component into water.

Chemical action can also be used to nullify azeotropic behavior by altering the volatility of one component. Examples are the use of solid sodium hydroxide, calcium oxide, or anhydrous calcium chloride to remove water from an organic solvent in the form of an immiscible aqueous solution. This produces an organic solvent of a purity greater than the azeotropic composition. The caustic or salt solution may be evaporated so the sodium hydroxide, calcium oxide, or calcium chloride can be reused. The sodium hydroxide solution can also be used as a reactant.

[24/] Another method of circumventing azeotropes which is not commonly used is to add a salt to reduce the vapor pressure of the component in which the salt is more soluble. For example, potassium acetate can be so used in separating ethanol from water .

Multicomponent mixtures

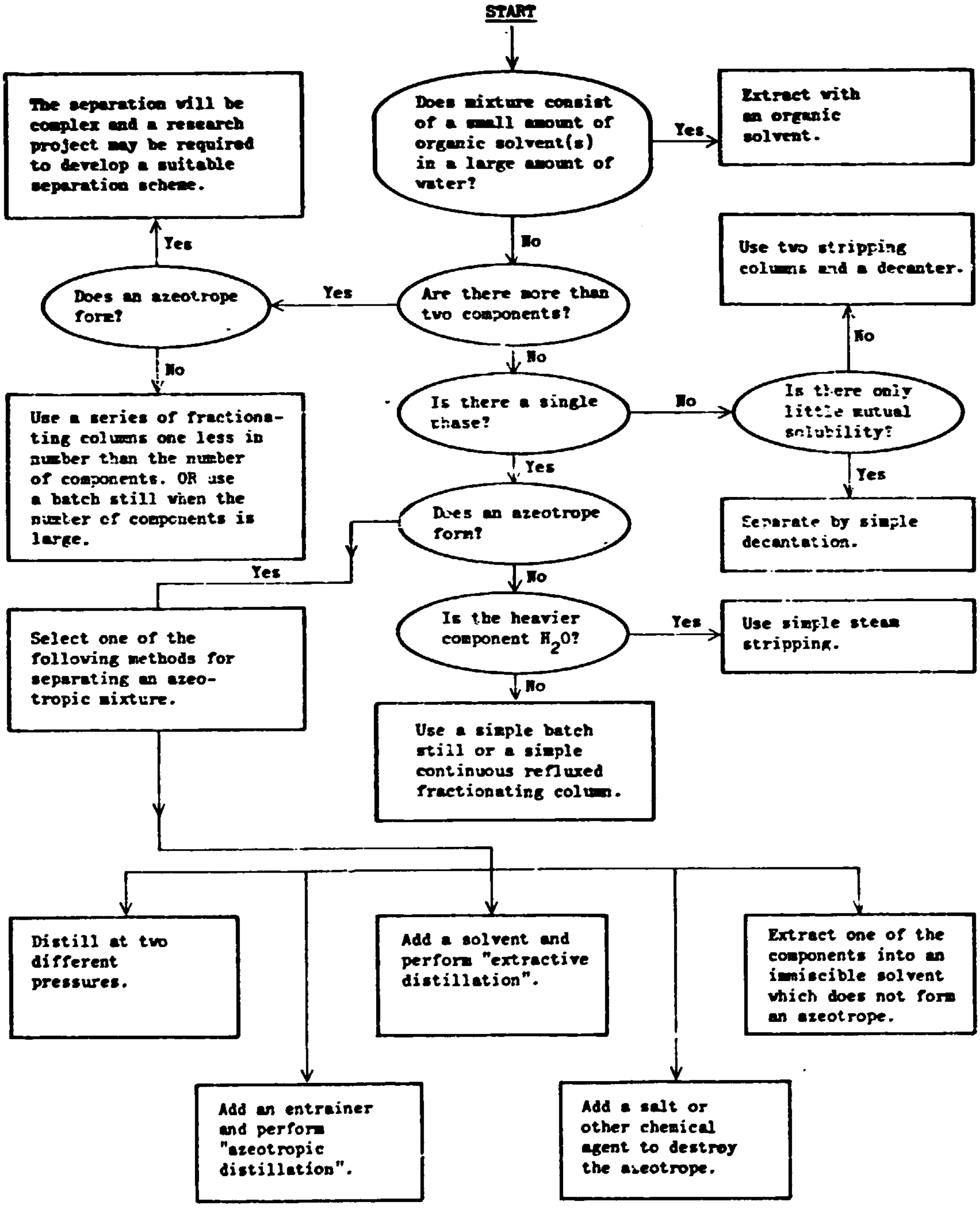
When no azeotropes form distillation columns can be used in series. The number of columns needed is one less than the number of components to be separated. When the number of components is large it may be less expensive to use batch distillation because only one apparatus is required for any number of products. If batch distillation times of at least 12 hours can be used[25/] the cost of start up and shut down can be relatively unburdensome and batch systems up to about 38,000 liters capacity are common.

Usually multicomponent systems are rather complex and several binary and multicomponent azeotropes can occur. Complete separations of such complex systems may be extraordinarily difficult. In the worst cases it may not be technically or economically feasible to separate more than several impure fractions of different boiling-point ranges, as is done in refining petroleum to make fuels. This is usually not acceptable in the pharmaceutical industry unless the solvent mixture is sold outside for fuel. In such cases each different mixture may require laboratory experimentation to develop a purification process because insufficient data will be available for design calculations. Such processes can entail combinations of continuous and batch rectification, decanting, multistage extraction and chemical treatment. For example, methanol-toluene-water can be separated by combined rectification decantation and separate stripping steps; MEK-toluene-water can be separated by combined single-stage extraction, continuous rectification and batch rectification; ethanol-ethyl acetate-water involves three binary azeotropes and requires multistage fractional extraction, binary rectification and azeotropic rectification. Figure 4 illustrates, in the form of a decision tree, the kind of thinking which underlies the development and design of a solvent separation/purification system.[26/]

[25/] Drew, J.W., "Solvent Recovery", Handbook of Separation Techniques for Chemical Engineers. McGraw-Hill Book Company, New York, New York, USA, 1979, p. 1-211.

[26/] Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387).

Figure 4. Decision tree for solvent separation



Source: Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387). p. 63.

With complex solvent mixtures (tertiary, quarternary), there is a research engineering laboratory at the Chinoin Pharmaceutical Company to work out separation procedures. Chinoin also uses extraction in different recovery processes but finds it is more expensive.[27/]

Operating conditions for solvent recovery by rectification

Operating conditions for rectification are dependent upon the particular waste solvent and its desired purity after reclamation. Solvents with high boiling points are most effectively distilled under vacuum. This reduces heating requirements since the solvent boiling point is lowered by presence of a vacuum in the evaporator. A vacuum can be achieved by vacuum pumps or steam ejectors. The distillation rate must be carefully controlled if contaminants are not to be carried over into the condenser. Temperature control is also necessary since excessive heat may decompose the solvent or solvent mixture. Purity requirements for the reclaimed solvent will determine the number of theoretical plates needed in the distillation column, reflux ratios, and processing time.

Purification

After rectification, water is removed from solvent by decanting or salting. Decanting is accomplished with immiscible solvent and water which, when condensed, form separate liquid layers, one or the other of which can be drawn off mechanically. Additional cooling of the solvent-water mix before decanting increases the separation of the two components by reducing their solubility. In salting, solvent is passed through a bed of anhydrous salt, such as calcium chloride, where water is removed by absorption.

27/ Chinoin Pharmaceutical and Chemical Works, Ltd., Budapest, Hungary. Unpublished data, 1986.

2.4 Activated carbon in solvent recovery

Adsorption of organic vapors on activated carbon is very efficient. No other adsorbents have been found as desirable. Ultimate retentivity of activated carbon for organic vapors can exceed 30 per cent of its weight and removal in excess of 98 per cent is possible. In practice, however, most economical operation occurs at a solvent loading of 5 to 20 per cent, while practical removal efficiencies are 80 to 95 per cent.[28/,29/,30/] All organic vapors having molecular weights greater than the apparent molecular weight of air can be adsorbed; the higher the molecular weight the more readily adsorbed is the solvent. Adsorption of mixed vapors is practical but some separation of components occurs in the bed, the adsorption taking place roughly as the inverse of the volatilities. This means a somewhat reduced capacity for the bed when compared with a single vapor.

Desorption and regeneration of the carbon is carried out by heating. Usually this is done by steam, resulting in a mixture of solvent and steam which is easily condensed. Hot gas may also be used. Since the quantity of hot gas needed is much less than that of the original air, a concentration of the vapor and transfer to another gas takes place. Desorption may also be carried out or aided by vacuum, but practical applications have been few, probably because of the added expense to make all equipment suitable for vacuum and the difficulty of transferring the necessary heat through the bed under vacuum. Hot-gas or vacuum regeneration processes also have the disadvantage of removing moisture from the bed. Moisture is an important factor in controlling bed temperature.

28/ Bateman, G.E., Zoss, S.J., and Hohenstein, G.A. "Organic solvent recovery. A cost savings and energy conservation approach to recovering waste streams." Industrial Wastes, November/December 1982, pp. 8-11.

29/ Kenson, R.E. "Carbon adsorption of hydrocarbon emissions using vacuum stripping." Pollution Engineering, July 1979, pp. 38-40.

30/ Wilkins, C.S.H. "Solvent recovery by activated carbon." Pollution Monitor, No. 2, 1981, pp. 7-8.

One practical example, however, of a vacuum stripped system is an American pharmaceutical manufacturer.[31] The pharmaceutical plant wished to control solvent fumes emitted from its tablet coating operations. The solvents were a mixture of methylene chloride and a water-soluble proprietary formulation. To avoid air pollution problems, and also to avoid azeotropic distillation of the proprietary solvent, the pharmaceutical manufacturer chose a vacuum stripped activated carbon adsorption system instead of a steam stripped system. A system was designed using two horizontal adsorption tanks with horizontal carbon beds.

In Hungary, the Vegyterv Engineering Company has an activated carbon recovery unit in the design stage for Biogal Pharmaceutical Company but it has not yet been put into operation. This is more for environmental protection (against air pollution) than for solvent recovery. Activated carbon recovery units are more effective for continuous production equipment rather than batch operations, according to Vegyterv.[32]

2.5 Collection and treatment of solvent vapours

In the pharmaceutical industry, the collection and treatment of solvent vapors usually takes place whenever product drying occurs under vacuum. The pharmaceutical industry attempts to dry products under vacuum whenever possible and recover the solvent vapors. For example, this is carried out by the Gedeon Richter plant in Dorog, presently with imported equipment.[33] Domestically produced equipment is being tested at the pilot stage at the Gedeon Richter plant in Budapest and at the Chinoin Pharmaceutical Company. Mostly the Chinoin products are air dryed, with concomitant loss of solvents.[34]

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[31] Kenson, R.E. "Carbon adsorption of hydrocarbon emissions using vacuum stripping." Pollution Engineering, July 1979, pp. 38-40.

[32] Vegyterv Engineering Company, Budapest, Hungary. Unpublished data, 1986.

[33] Gedeon Richter Pharmaceutical Company, Budapest, Hungary. Unpublished data, 1986.

[34] Chinoin Pharmaceutical and Chemical Works, Ltd., Budapest, Hungary. Unpublished data, 1986.

Solvents may be absorbed or adsorbed but are generally not recovered. In special cases products are dryed under vaccum, and about 70 per cent of the solvent can be recovered. At the Janssen Pharmaceutical plant in Belgium, the situation is different at the two production sites.[35/] At the older plant in Beerse all solvent is lost during drying of products. However, at Geel, the new Janssen production site, the equipment allows drying of products under vacuum and most solvent vapors are recovered.

Solvents present in the gas phase are initially treated by vapor recovery. Vapor recovery entails removal of solvent vapors from a gas stream in preparation for further reclaiming operations.[36/]

The initial treatment method chosen depends upon the factors listed below:

- solvent vapor composition
- air concentration of gas stream
- solvent boiling point
- solvent reactivity
- gas stream composition
- solvent vapor concentration
- solvent solubility

Absorption, adsorption and condensation are initial treatment techniques used for collecting solvent vapors from gas streams.

Condensation of solvent vapors is accomplished by water-cooled condensers and refrigeration units. Condensers are capable of reaching temperatures of 15°C, while refrigeration units can reach 10°C. The feasibility of condensation for vapor recovery is dependent upon solvent concentration and the temperature required for condensation. For adequate recovery, solvent components must be above the saturation concentration at the condensing temperature. A solvent vapor concentration well above 20 mg/m^3 is required for effective recovery of solvent vapors by condensation.

[35/] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

[36/] United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratory, Cincinnati, Ohio, USA, April 1978, p. 8.

, To avoid explosive mixtures of certain solvent and air in the process gas stream, air can be replaced with an inert gas such as nitrogen. This is costly, however. Solvent vapors which escape condensation are recycled through the main process stream or recovered by further initial treatment with adsorption or absorption. Solvent vapors may then be further recovered by adsorption on activated carbon as explained in Section 2.4.

Absorption of solvent vapors by a liquid medium provides an alternative to adsorption schemes. The waste gas stream is passed through a liquid by means of scrubbing towers or spray chambers. Absorption of water-soluble solvents in water is often suggested. Most common solvents have rather high vapor pressure. Furthermore, their high partial pressures from dilute aqueous solutions means that very large quantities of water have to be used to effect removal. As an example, recovery of 90 per cent of the acetone present in air at 25 per cent of the lower explosive limit would require an absorption column of 9 theoretical stages using a minimum of 1,500 kg of water per kilogramme of acetone recovered. Distilling the recovered solution of 0.067 per cent acetone would require a column of over 100 theoretical stages using 60 kg of steam per kilogramme of acetone so as to produce 99 per cent acetone overhead and water bottoms suitable for recycle to the absorber. Absorption in water is practical, however, for high-boiling water-soluble solvents such as dimethyl formamide, glycols, glycol ethers, and glycol amines. However, some of these azeotrope with water, complicating final purification.[37/]

Absorption in oil is often more practical than absorption in water, since activity coefficients in oil tend to be closer to unity, especially for nonpolar solvents. Mineral oils have been used as absorbing liquids, for example. Thus the ratio of oil to solvent need not be nearly as high as with water. However, losses of oil and stripping and recycling of the oil can be costly. The oil selected must have a low vapor pressure so as to minimize losses in the air leaving the absorber. Such oils have high molecular weights

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[37/] Drew, J.W., "Solvent Recovery", Handbook of Separation Techniques for Chemical Engineers. McGraw-Hill Book Company, New York, New York, USA, 1979, p. 1-204.

and viscosities well above that of water, which results in low stage efficiency in the absorber and low coefficients of heat transfer. Large absorption and heat-exchange equipment is therefore required. Absorption in oil is considered only where adsorption on carbon is not practical.[38/]

2.6 Economics of solvent recovery

The Janssen Pharmaceutical Company has noted that solvents are getting progressively more expensive. Therefore they find it economical to recover solvents whenever possible. Similarly, the Gedeon Richter Pharmaceutical Company recovers solvents mostly because it is good economics. New solvents are expensive! Recovering costs for solvents are much lower than purchase prices for new solvents. Furthermore, the waste solvents cannot simply be discharged to the environment. This is contrary to the law in industrialized countries (including Belgium and Hungary) and many developing countries. At the Chinoin Pharmaceutical Company, in general, it is also more expensive to buy solvents than to regenerate them. However, the exception is methanol, which is cheaper to buy than to regenerate.[39/]

The costs of twenty-four organic solvents used by Janssen Pharmaceuticals are presented in Table 5.[40/] Corresponding values of recovered solvents are also shown. Janssen recovered solvents equal in value to about 42 per cent of solvent expenditure for production and general purpose uses. The sum of columns 1 and 2 in Table 5 does not quite equal that of columns 3 and 4 due to imprecisions in internal solvent accounting.

Costs of 17 solvents used in pharmaceuticals production by Gedeon Richter in 1985 are shown in the last column of Table 6. Twelve out of these 17 solvents increased in price from 1983 to 1985 as shown in Table 7.[41/]

[39/] Chinoin Pharmaceutical and Chemical Works, Ltd., Budapest, Hungary. Unpublished data, 1986.

[40/] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

[41/] Gedeon Richter Pharmaceutical Company, Budapest, Hungary. Unpublished data, 1986.

Table 5. Cost figures associated with various solvents (in US$),[a] Janssen Pharmaceutical Company

Solvent	Cost of solvents used in production	Cost of solvents for general use (cleaning, etc.)	Value of recovered solvent	Value of lost solvent
Acetone	43,572	31,173	25,474	49,271
Chloroform	37,889	11,150	23,181	25,857
1,2-Dichloroethane	58,441	721	8,168	50,994
Dimethylacetamide	12,144	169	-	12,145
Dimethylformamide	49,195	899	265	49,829
Ethylacetate	29,929	32	17,011	12,950
Ethanol	48,162	1,164	8,230	41,096
2-Propanol	76,558	1,623	51,973	26,208
Methanol	49,090	1,010	8,443	41,657
Dichloromethane	9,936	411	4,586	5,761
Methylisobutylketone	61,379	846	38,695	23,530
Tetrahydrofuran	105,097	512	44,604	61,005
Toluene	84,856	5,213	55,112	34,957
Dimethylbenzene	13,847	697	8,674	5,870
Benzene	2,586	-	-	2,586
1-Butanol	588	-	-	588
Chlorobenzene	27,383	-	22,430	4,952
Cyclohexanol	1,149	-	133	1,016
1,2-Dichlorobenzene	7,707	-	5,461	2,246
Ethylbenzene	50	-	-	50
Fluorbenzene	11,740	-	-	11,740
2-Butanone	10,133	-	6,848	3,284
1,1,2,2-Tetrachloroethylene	437	-	387	50
Heptane 50%	920	-	-	920
Methylisobutylketone/Toluene	-	-	4,644	-4,644[b]
TOTAL	742,799	55,624	334,326	464,098

cont.

Table 5 cont.

US$ 51,700 are used for maintenance

US$ 28,660 - Acetone
US$ 13,600 - Chloroform
US$ 9,439 - Ethanol

Ammonia	3,609	28
NaOH 50%	7,437	6,754
HCl	6,229	167
TOTAL	17,275	6,949

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a/ Belgian francs converted to US$ on the 1985 average exchange rate of BF 59.38 = US$ 1.00. Monthly Bulletin of Statistics, United Nations. ST/ESA/STAT/SERQ/159, March 1986.

b/ In some reactions there is an input of fresh methylisobutylketone and fresh toluene. At the end of the reaction, a mixture of the two solvents is recovered (a total of 11,990 liters in 1985). That accounts for the negative figure in the column "Value of list solvent".

Source: Janssen Pharmaceutica, Beerse, Belgium, October 1985.

Table 6. Amounts and values of solvents used in chemical production, Gedeon Richter Pharmaceutical Company (1985)

Solvent	Pure solvent liters/year	Recovered solvent liters/year	Total solvent liters/year	Price US$/liter[a/],[b/]	Total value US$
Acetone	1,025,000	405,000	1,430,000	0.38	543,000
Benzene	3,072,000	1,581,000	4,654,000	0.30	1,396,000
n-Butanol	308,000	456,000	765,000	0.38	290,000
Diethylene glycol	809,000	-	809,000	0.71	574,000
1,2-Dichloroethane	340,000	1,943,000	2,283,000	0.42	958,000
Dimethylformamide	1,582,000	-	1,582,000	0.64	1,012,000
Ethyl acetate	944,000	888,000	1,832,000	0.65	1,190,000
Ethanol	2,913,000	1,228,000	4,142,000	0.33	1,366,000
Ethylene glycol	450,000	-	450,000	0.53	238,000
Chlorobenzene	14[illegible]00	99,000	244,000	0.56	136,000
Chloroform	98[illegible],000	1,146,000	2,130,000	0.42	894,000
Methanol	[illegible]4,[illegible]47,000	3,664,000	18,511,000	0.13	2,406,000
Dichloromethane	256,000	150,000	407,000	0.53	215,000
Isopropanol	534,000	330,000	865,000	0.41	354,000
Tetrahydrofuran	247,000	154,000	401,000	1.44	578,000
Toluene	911,000	1,361,000	2,272,000	0.23	522,000
Xylene	126,000	-	126,000	0.24	30,000
TOTAL					

a/ Hungarian Forint converted to US$ on the 1985 average exchange rate of Forint 50.726 = US$ 1.00. Monthly Bulletin of Statistics, United Nations. ST/ESA/STAT/SERQ/159, March 1986.

b/ Volumes in liters were calculated from kilograms using densities obtained from the Handbook of Chemistry and Physics, 51st Edition. Physical Constants of Organic Compounds Table. The Chemical Rubber Company, Cleveland, Ohio, USA, 1971.

Source: Gedeon Richter Pharmaceutical Company, Budapest, Hungary, January 1986.

Table 7. Variations in purchase and price of solvents, Gedeon Richter Pharmceutical Company, 1983-1985

Solvent	Change in prices US$/liter[a/], [b/]		
	1983	1984	1985
Acetone	0.43	0.35	0.38
Benzene	0.29	0.29	0.30
n-Butanol	0.45	0.38	0.38
Diethylene glycol	0.63	0.68	0.71
1,2-Dichloroethane	0.47	0.42	0.42
Dimethylformamide	0.88	0.79	0.64
Ethyl acetate	0.59	0.64	0.65
Ethanol	0.36	0.33	0.33
Ethylene glycol	0.53	0.52	0.53
Chlorobenzene	0.63	0.56	0.56
Chloroform	0.48	0.37	0.42
Methanol	0.14	0.12	0.13
Dichloromethane	0.64	0.58	0.53
Isopropanol	0.36	0.33	0.42
Tetrahydrofuran	1.62	1.52	1.44
Toluene	0.23	0.22	0.23
Xylene	0.27	0.24	0.24

a/ Hungarian Forints converted to US$ on the following average exchange rates: Monthly Bulletin of Statistics, United Nations. ST/ESA/STAT/SERQ/159, March 1986.

Forints 50.726 = US$ 1; 1985
Forints 51.199 = US$ 1; 1984
Forints 45.193 = US$ 1; 1983

b/ Volumes in liters were calculated from kilograms using densities obtained from the Handbook of Chemistry and Physics, 51st Edition. Physical Constants of Organic Compounds Table. The Chemical Rubber Company, Cleveland, Ohio, USA, 1971.

<u>Source</u>: Gedeon Richter Company, Budapest, Hungary, January 1986.

In the case of Janssen, 17 out of the 23 solvents for which comparisons could be made increased in price from 1983 to 1985. These data are presented in Table 8.[42/]

Solvent costs for cleaning small equipment and reactor at Janssen are shown in Table 9.[43/] The detailed breakdown of usage of acetone, chloroform and ethanol is given in Table 10.[44/] These represent not quite ten per cent of the costs incurred by Janssen for solvents used in production.

[42/] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

[43/] *Ibid.*

[44/] *Ibid.*

Table 8. Value of solvents over the period 1983-1985 (US$/liter)[a/], Janssen Pharmaceutical Company

Solvent	1983		1984		1985	
	Pure	Recovered*	Pure	Recovered*	Pure	Recovered*
Acetone	0.43	0.43	0.30	0.30	0.33	0.33
Benzene	0.44	0.44	0.38	0.38	0.45	0.45
1-Butanol	-	-	-	-	0.27	0.27
2-Butanone	-	-	-	-	0.45	0.45
Chlorobenzene	0.70	0.70	0.56	0.56	0.61	0.61
Chloroform	0.46	0.34	0.52	0.41	0.60	0.45
Cyclohexanol	0.84	0.84	0.68	0.68	0.75	0.75
1,2-Dichloroethane	0.35	0.27	0.29	0.23	0.29	0.29
1,2-Dichlorobenzene	-	-	-	-	1.18	1.18
Dibutylether	1.56	1.56	1.35	1.35	1.31	1.31
Dimethylacetamide	-	-	-	-	1.83	1.83
Dimethylbenzene	-	-	-	-	0.31	0.20
Dimethylformamide	0.72	0.72	0.68	0.68	0.68	0.68
Ethanol	0.48	0.48	0.34	0.34	0.56	0.56
Ethylacetate	0.50	0.50	0.47	0.47	0.61	0.61
Ethylbenzene	0.78	0.78	0.73	0.73	0.64	0.64
Fluorobenzene	8.02	8.02	7.72	7.72	8.58	8.58
Heptane 90%	0.17	0.17	-	-	0.20	0.20
Heptane 50%	0.37	0.37	0.32	0.32	0.34	0.34
Methanol	0.17	0.12	0.14	0.10	0.14	0.03
Methylenechloride	0.64	0.56	0.60	0.53	0.60	0.47
Methylisobutylketone	0.68	0.55	[illegible]	0.47	0.61	0.37
2-Propanol	0.45	0.45	0.31	0.31	0.38	0.38
Tetrahydrofuran	1.66	1.23	1.54	1.54	1.64	1.35
1,1,2,2-Tetrachloroethylene	-	-	-	-	0.73	0.73
Toluene	0.34	0.25	0.27	0.37	0.32	0.21

* Value of solvent recovered from production reactors without sending it to distillation tower.

a/ Belgian francs converted to US$ on the following average exchange rates: BF 51.13 = US$ 1.00, 1983
Monthly Bulletin of Statistics, United Nations. BF 57.78 = US$ 1.00, 1984
ST/ESA/STAT/SERQ/159 BF 59.38 = US$ 1.00, 1985

Source: Janssen Pharmaceutica, Beerse, Belgium, October 1985.

Table 9. Costs of solvents (acetone, chloroform and ethanol) used for cleaning small equipment and reactors at the Janssen Pharmaceutical Company (US$)a/

	Costs 1982	Costs 1983	Costs 1984
Cleaning small equipment	85,435	49,685	16,922
Cleaning reactors	71,489	57,596	36,209
TOTAL	156,924	107,281	53,131
		Acetone	29,454
		Chloroform	13,977
		Ethanol	9,700
			53,131

a/ Belgian francs converted to US$ on the following exchange rates:
BF 57.78 = US$ 1.00; 1984
BF 51.13 = US$ 1.00; 1983
BF 45.69 = US$ 1.00; 1982
Monthly Bulletin of Statistics, United Nations. ST/ECA/STAT/SERQ/159, March 1986.

Source: Janssen Pharmaceutica, Beerse, Belgium, October 1985.

Table 10. Use of solvents for maintenance at the Janssen Pharmaceutical Company (in liters)

Acetone	Pure solvent used to clean small equipment:	421
	Recovered solvent used to clean small equipment:	30,699
	Pure solvent used to clean reactors:	41,668
	Recovered solvent used to clean reactors:	23,201
Chloroform	Pure solvent used to clean small equipment:	450
	Recovered solvent used to clean small equipment:	70
	Pure solvent used to clean reactors:	20,630
	Recovered solvents used to clean reactors:	6,770
Ethanol	Pure solvent used to clean small equipment:	-
	Recovered solvent used to clean small equipment:	20,490
	Pure solvent used to clean reactors:	2,300
	Recovered solvent used to clean reactors:	5,180
		151,879 (US$ 53,131)

small equipment ---------------- 52,130

reactors ---------------- 99,749

Source: Janssen Pharmaceutica, Beerse, Belgium, October 1985.

3. HEAT RECOVERY FROM INCINERATION

3.1 Incineration of waste solvents

An additional economic incentive for recovery is the cost incurred for disposal of non-recoverable solvents. In the case of Janssen Pharmaceuticals, these are usually trucked to a port and burned at sea at a cost of US$ 135 - US$ 2,000 per ton.[45/] On the other hand, the Gedeon Richter pharmaceutical company in Hungary sells waste solvents for incineration in the Vienna, Austria municipal incinerator. Annually, two or three hundred tons of waste solvents (ethyl alcohol, methyl alcohol, isopropyl alcohol, butyl alcohol (mixed isomers) benzene (any slightly contaminated, non-chlorinated solvents not containing active pharmaceutical ingredients)) are sold to the Vienna municipal incinerator for increasing calorific value. The calorific value of the solvents must be at least 5,000 calories/kilogramme.[46/]

Presently, 800 tons/year of waste solvents from Gedeon Richter are burned in incinerators operated by other industries in the neighbourhood of Budapest. Another 800 tons of slightly contaminated solvents are sent to other industries, especially the dye industry in Budapest.[47/] Presently Chinoin has a great problem with solid wastes disposal. They have sent wastes for incineration to Vienna and to France. Both of these solutions are very costly. Chinoin, Richter and EGIS (another Hungarian firm) are jointly building an incinerator in Budapest. Any unrecoverable solvents will be burned in this incinerator. Gedeon Richter now stores 450 tons/year of contaminated halogenated solvents pending the completion of the new incinerator. The incinerator will operate at temperatures high enough to destroy halogenated solvents and will be equipped with facilities to neutralize the corrosive HCl and HBr fumes released from the solvent.[48/]

[45/] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

[46/] Gedeon Richter Pharmaceutical Company, Budapest, Hungary. Unpublished data, 1986.

[47/] *Ibid.*

[48/] *Ibid.*

Table 11 shows the combined total of solvents sent to either the sewer or for incineration by Janssen. Although the breakdown of incineration of individual solvents is not available, Janssen reports that a total of 750,000 liters of waste solvents were incinerated in 1984.[49]

Resource Recycling Technologies Inc. (Madison, Tennessee) is a large company with a plant to convert waste solvents into a synthetic No. 2 fuel oil. The solvent conversion facility is operated by a subsidiary, Chem-Fuel Inc. (Portland, Tennessee). Chem-Fuel will receive industrial solvents from eight southern states, resulting in the daily conversion of 150,000 liters of waste solvents into fuel.[50]

Solvents accepted for conversion include alcohols, ketones, glycols, acetals and aromatics, but not chlorinated hydrocarbons. The resultant synthetic fuel will sell for 10 per cent less than the price of standard No. 2 fuel oil. The standard No. 2 fuel oil product has a heating value of about 9,450 kcal per litre and sold for $0.24 per litre in 1981.

Unlike solvent recyclers that custom-clean a client's batch of waste solvents, the Chem-Fuel operation is based on a mixed solvent stream. Mixed waste solvents are first filtered to remove solids, and the solvent is then subjected to vacuum distillation. The purpose is to obtain a mixture suitable for use as a fuel, not pure solvents to be re-used in production operations.

The still bottoms and filtered solids are incinerated. The clean liquid solvent from the distillation process then undergoes a low-pressure, low-temperature reduction reaction to produce the synthetic oil base. Some industry observers, however, question the economics of turning all the waste solvent into oil when many of the solvents are of much higher economic value than fuel oil.

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[49] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

[50] Pollution Probe Foundation. Profit from Pollution Prevention, A Guide to Industrial Waste Reduction and Recycling. Washington, D.C., USA (undated), p. 244.

Table 11: Amounts of solvents sent to the sewer system or incineration (in liters) by the Janssen Pharmaceutical Company

Acetone	165,018
1-butanol	2,118
2-butanone	7,616
Benzene	6,927
Chlorobenzene	9,071
Chloroform	37,874
Cyclohexanol	1,522
1,2-dichloroethane	169,525
1,2-dichlorobenzene	1,991
Dichloromethane	8,876
Dimethylacetamide	6,964
Dimethylbenzene	15,402
Dimethylformamide	75,118
Ethanol	121,773
Ethylacetate	27,832
Ethylbenzene	70
Fluorobenzene	1,523
Heptane 50%	2,885
Methanol	282,881
4-methyl-2-pentanone	27,168
Methylisobutylketone/Toluene	11,990
2-propanol	85,743
1,1,2,2-tetrachlorcethylene	97
Tetrahydrofuran	40,484
Toluene	71,835
Ammonia	37,298
Sodiumhydroxide 50%	126,908
Hydrochloric acid	91,973
TOTAL	1,414,502

Source: Janssen Pharmaceutica, Beerse, Belgium, October 1985.

3.2 Incineration of waste solvent residues

The Hukill Chemical Corporation (Bedford, Ohio, USA) has been in the solvent recovery business for more than 30 years. Many solvent recyclers are wondering how to dispose best of the 20 per cent residue remaining from the recycling process. However, Hukill is well on the way to marketing a residue byproduct as a fuel supplement.[51/] "We try to close the loop by reclaiming the solvent, residue and the drums", says Emory Hukill, President. The residue is blended with other hydrocarbons to make it equivalent in terms of kcalories to No. 6 fuel oil. The fuel supplement is then sold to the cement industry. Kilns at a cement company operate at about 1,650°C which is a high enough incineration temperature to destroy stray halogenated hydrocarbons.

For Hukill, it is clear that economic considerations first drove him to re-evaluate previous residue disposal practices. At a cost of $0.31 per litre to bury the residue, landfilling is the most expensive disposal option. Sales of solvent residues as a fuel on the other hand have produced revenue of $0.04 per litre. A cost comparison of residue disposal options at Hukill Chemical (1981) is shown below:[52/]

Cost of burying residues	Present revenue from fuel sales
$0.0055/1	$0.0007/1
$0.31/1	$0.04/1
$696,000/year*	$90,000/year[a/]

a/ These numbers are based on the assumption that 20 per cent of the 3 million gallons of solvent handled annually result in residue. Every firm which carries out solvent recovery will have some residue. This can either be incinerated on site, sold as a fuel or disposed in a secure landfill.

Hydrachem Corp. (Dallas, Texas, USA), in conjunction with the United States Department of Energy, plans to build a plant to produce both recycled

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[51/] Pollution Probe Foundation. Profit from Pollution Prevention, A Guide to Industrial Waste Reduction and Recycling. Washington, D.C., USA (undated), p. 245.

[52/] *Ibid*, p. 244.

solvents and fuel oil.[53/] Spent solvents such as xylenes, toluenes and other aromatics will be accepted from various industries. Hydrachem will reclaim as solvents 20 to 25 per cent of the waste solvent stream and recover 55 to 60 per cent as synthetic fuel roughly equivalent to No. 4 fuel oil (heating value of approximately 6,660 kcal/liter and worth $0.12/liter in 1981).

The 20 per cent residue from the recovery process will be pyrolized in the future to obtain a saleable gas of low caloric value. Current disposal costs for the residue are about $0.13 per liter.

The Janssen Pharmaceutical Company hopes to send toxic solvent wastes to Antwerp in future years.[54/] The Belgian government is in the process of establishing a large waste treatment facility. The government intends to put up 57 per cent of the capital and Belgian industry will supply the other 43 per cent. There will be waste water treatment facilities and facilities for incinerating toxic wastes.

[53/] Pollution Probe Foundation. Profit from Pollution Prevention, A Guide to Industrial Waste Reduction and Recycling. Washington, D.C., USA (undated), p. 245.

[54/] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

4. GENERAL CONSIDERATIONS REGARDING SOLVENTS AND WASTE WATER TREATMENT

4.1 General remarks

A very important general rule is to keep out of the waste waters any component it is possible to keep out.[55/] For example, organic solvents should not be allowed to enter wastewaters and mycelia from fermentation should be carefully filtered from the broth. Solvents should be recovered and re-used. Any organic solvents that are in aqueous wastes should be stripped out to the greatest extent possible before sending the wastewaters to equalization and biological treatment. Such solvent recovery not only saves raw materials costs but also reduces waste-treatment costs. Organic solvents are such high strength wastes that it is generally considered good practice to install automatic devices for monitoring wastewaters streams for excess solvents that could arise from spills, leaks or other malfunctions. Alarms connected to the monitors can provide warning in sufficient time to intercept and prevent high concentrations of solvent from flowing to equalization or biological treatment steps.

For example, Janssen Pharmaceuticals employs a variety of organic solvents in many syntheses. Many of the syntheses are capable of imparting a shock load to the operation of the waste water treatment plant. Therefore whenever a solvent is used alone in a chemical synthesis, it is recovered and recycled, if possible. Recovery of 17 solvents at Janssen was discussed in Section 2.6.

An exception to the above remarks is the case of biodegradable solvents which are not economically recoverable because the cost of recovery approaches or exceeds the price of virgin solvent. As an illustration, the Gedeon Richter Company in Hungary sewers waste methanol.[56/] One major difficulty at Janssen Pharmaceutical Company in solvent recovery is recovery of

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[55/] Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387).

[56/] Gedeon Richter Pharmaceutical Company, Budapest, Hungary. Unpublished data, 1986.

alcohol-water mixtures.[57] In particular, the cost of recovery of ethanol is approaching the cost of buying the pure alcohol. Ethanol-water mixtures are biodegradable, therefore solvent-water mixtures are sent in metered quantities to the waste treatment plant.

Janssen sewers eight other solvents as shown in Table 12.[58] Six of the total are biodegradable organics. The other three are inorganic and are discharged in metered amounts to keep the pH of the waste water within desirable limits.

At Janssen the waste solvents are either discharged to the sewage system or to a separate collection system from the one which receives waste waters. The waste solvents which are not sewered are collected and disposed by incineration.

As another example, the following measures to improve waste water treatment operations were recommended to Bristol Laboratories at its fermentation plants in Syracuse, NY:[59]

- Remove formaldehyde from wastes to prevent bacterial inhibition in the waste treatment
- Sample and test all wastewaters for the presence of organic solvents
- Install stripping towers to remove solvents from wastewaters.
- Remove all mycelium
- Eliminate process leaks
- Carefully programme and monitor the discharge of fermentation wastes
- Neutralize acid wastes
- Provide waste equalization
- Inform management of the wastewater treatment plant of any changes in process operation that might affect the amount and properties of the wastewaters

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[57] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

[58] Ibid.

[59] Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387). p. 70.

Table 12. Amounts of solvents sent to the sewage treatment plant (in liters), Janssen Pharmaceutical Company

Solvents	Liters
2-Propanol	42,800
Acetone	104,000
Chloroform	22,000
Ethanol	60,800
Methanol	140,000
Dimethylformamide	37,500
Ammonia	38,000
Sodiumhydroxide 50%	127,000
Hydrochloric acid	92,000
TOTAL	664,100

Source: Janssen Pharmaceutica, Belgium, October 1985.

4.2 Waste water treatment technology

Biological waste treatment is the most commonly used method of purifying wastewaters from modern, drug-manufacturing plants. In these treatment technologies a mixture of microorganisms converts a waste of complex organic molecules into simple products (such as CO_2 and H_2O) and into additional biological cell mass. There are two major biological treatment processes used to oxidatively purify wastewaters from drug manufacture: the activated sludge process and the trickling-filter process, each of which is described below.

4.3 Activated sludge treatment[60/]

The treated wastewater from this process is separated by gravity from the sludge (a solid mass containing microorganisms). A portion of the sludge is recycled to the beginning of the process where it is mixed with incoming wastewater and oxygen from the air. In simple terms, the sludge oxidizes a portion of the biodegradable organic compounds in the wastewater feed to CO_2 and H_2 and incorporates the rest into new sludge. Both soluble and suspended organic matter can be removed from the water by such reactions.

Activated-sludge systems use an aeration vessel followed by a settling vessel where the sludge is separated. These vessels are connected by a pipe through which a portion of the settled sludge is recycled to the aeration vessel (Figure 5).[61/] Wastewater leaving the primary settler (which may also serve as an equalization basin) is mixed with recycled sludge and the mixture enters one end of a rectangular aeration vessel. As the mixture flows through the aeration vessel it is charged with air bubbles and the organisms in the activated sludge oxidize the organic wastes to gases, to additional cell mass and to other oxidized compounds. The excess sludge formed during this process is removed. The recycled sludge is returned to the front of the process at a rate about equal to 25 - 35 per cent of the inlet wastewater flowrate. The microorganisms consume oxygen at a more rapid rate near the

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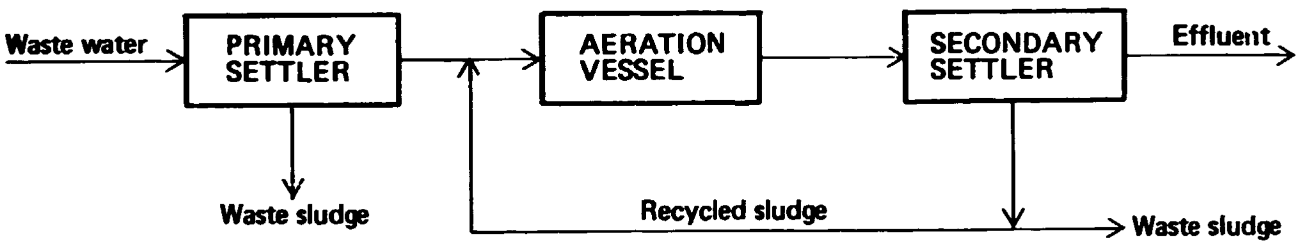
[60/] Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387). p. 79.

[61/] *Ibid*, p. 80.

Figure 5. Activated Sludge Process Flowsheet



Source: Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387). p. 80.

front end of the aeration vessel where the concentration of organic wastes is greatest. Thus the aeration rate can often be gradually reduced along the length of the aeration vessel provided the oxygen concentration in the liquid is kept at least at 2 mg/l.

Some important typical design parameters of activated sludge processes are as follows:[62/]

Loading = 0.32 - 0.64 kg BOD/m^3-day
Sludge age = 3 - 14 days
Residence time = 4 - 8 hours
Removal Efficiency = 85 - 95 per cent of the BOD; somewhat less of the COD
Solids Concentration = 1100 - 3000 mg MLSS/litre
Recycle Ratio (fraction of sludge recycled) = 0.15-0.75

The residence time is approximately the average time the wastewater spends in the aeration vessel. The sludge age is approximately the average time the solids spend in the system. Increasing the recycle ratio increases the sludge mean residence time.

There are a number of variations of the basic activated sludge process. For example, the conventional long, rectangular aeration tank ordinarily provides that the sludge-wastewater mixture passes through it in an approximation to plug flow. It is possible to substitute a cylindrical, mechanically-stirred aeration vessel for the rectangular tank, thereby providing a well mixed volume and a situation approximating perfectly back-mixed flow. The well mixed tank is more resistant to shock loads of BOD due to solvents in the feed wastewaters because it very rapidly dilutes abrupt concentration fluctuations.

Another relatively recent variation of the activated sludge process is to use pure oxygen rather than air to achieve higher rates of oxygen transfer and help maintain dissolved oxygen concentration above the critical value of

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[62/] Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387). p. 8'

2 ppm, even under conditions of shock loads.[63] A typical system is Union Carbide Corporation's UNOX process in which oxygen, wastewater and recycled sludge flow concurrently through several well mixed stages consisting of covered agitated tanks. To give one example, Lederle Laboratories installed a UNOX pure-oxygen process at its Pearl River N.Y. plant which produces fermentation products and biologicals. Pure oxygen systems can usually be designed based on a higher loading parameter than for air systems, in some cases up to about 1.0 mass BOD/mass MLSS - day. This permits more treatment capacity to be installed in the same volume. The capacity of an existing, conventional activated sludge system can thus be expanded without having to make substantial increases in aeration-tank capacity. On the other hand, this process requires a supply of pure oxygen, more highly trained operators and more maintenance than the more conventional biological oxidation processes. Pure-oxygen treatment processes will seldom be the solution to wastewater treatment problems for the pharmaceutical industry in developing countries.

4.4 Trickling filters[64]

Although their BOD removal efficiency is less and they require more land area, trickling filters cost less to operate and demand less skill of the operators who run them. For treating pharmaceutical wastes trickling filters are more common in England than in the U.S. When they are designed with large recycle ratios which provide large dilution rates, trickling filters are often able to withstand shock loads from solvents in the waste water.

A trickling filter is made up of a deep cylindrical bed of gravel, stone, stag, clinker, plastic forms or similar material usually in the size range of about 2.5 to 6.5 cm. In use, a layer of microbial growth forms on the surface of the packing material in depths ranging up to about two millimeters. It is this layer that absorbs the organic waste components from the water and oxidizes them under aerobic conditions. Both oxygen and waste molecules must diffuse into this film in order for biological oxidation to be accomplished. If the COD of the wastewater is less than about 400 - 500 mg/liter the rate of

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[63] Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387). p. 83.

[64] Ibid

oxidation is controlled by the rate of diffusion of organic material in the biological film. For larger COD values the rate of the process is limited and controlled by the rate of oxygen transport into the film. When such trickling filters are used to treat too high-strength industrial waste the interior of the microbial films can get depleted in oxygen and generate unpleasant odors associated with anaerobic microbial processes.

The flow scheme for using trickling filters is similar to activated sludge arrangements in that the process is preceded by a primary settler upstream and followed by a secondary settler. An important difference is that liquid effluent, rather than concentrated sludge, is recycled back to the front end of the trickling filter and mixed with wastewater feed. Figure 6[65/] shows this type of flow scheme for a single trickling filter with recycle of clarified effluent as well as a two-stage trickling-filter flow scheme in which the recycle pattern is more complex. Recycle ratios ranging from one to three are normal in order to insure sufficient flow through the filters to keep all portions of the packing wet. Such recycle also dilutes the feed thereby damping out shock load fluctuations in wastewater concentration. This is especially imporatant in pharmaceutical plants where solvents may be present in the waste water. Removal efficiencies for all well designed and operated trickling filters range from about 70 - 90 per cent removal of BOD.

4.5 Tertiary treatment methods

The initial operations to remove suspended solids from wastewater are often called primary treatment (e.g. primary settling). Biological oxidation with associated secondary settling of solids is usually called secondary treatment. Tertiary treatment is sometimes used to remove pollutants not removed from the wastewater by primary and secondary treatment. The most important tertiary processes are absorption on activated carbon and denitrification. For example, tertiary treatment at the Beerse, Belgium,

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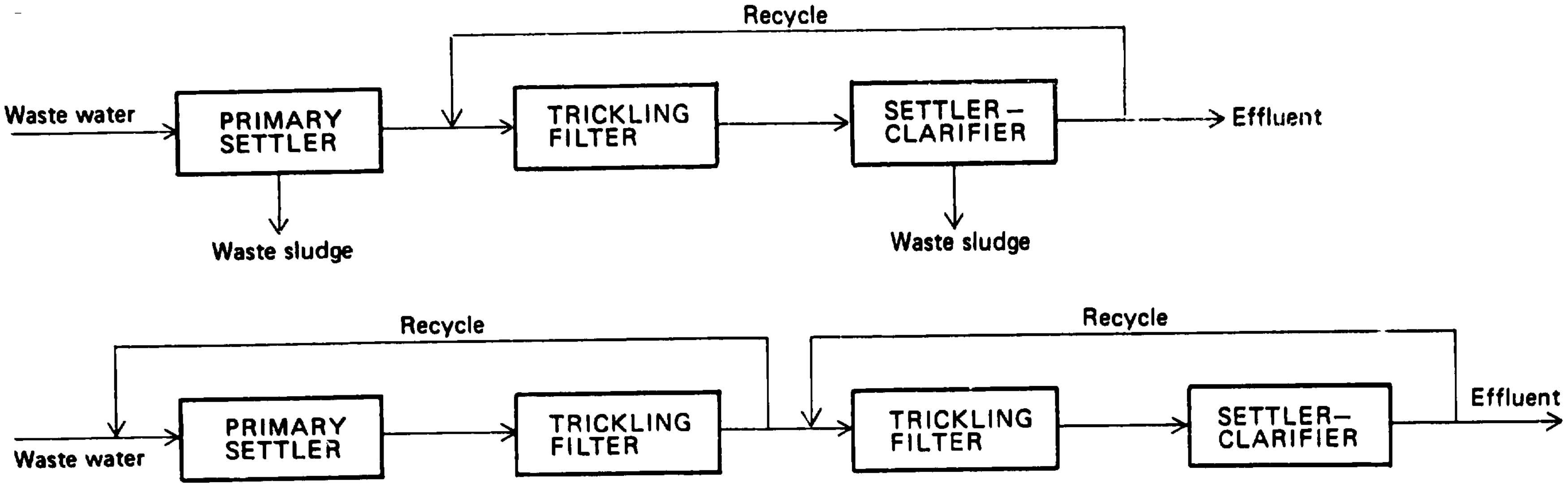
65/ Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387). p. 85.

Figure 6. Trickling Filter Effluent Treatment Flow Sheet



Source: Water use and effluent treatment practices for the manufacture of the 26 priority drugs in the UNIDO illustrative list. (Background paper for the Second Consultation on the Pharmaceutical Industry, Budapest, Hungary, 22-25 November 1983). (UNIDO/IS.387). p. 85.

plant of Janssen Pharmaceuticals consists of sand filtration, followed by contact with activated carbon and finally disinfection using ultraviolet light.[66/] This system has the capacity of accepting a maximum of 75 m^3/hour treated effluent from the activated sludge plant (about one third of the average dry weather flow). The activated carbon filtration step is designed to remove any solvents which have passed through the biological waste water treatment. A portion of this tertiary-treated water is used for cleaning and maintenance instead of being discharged. That portion of the tertiary-treated effluent not re-used by the company is mixed with the effluent from the activated sludge plant and discharged, thereby improving the quality characteristics of the discharged effluent.

Adsorption on activated carbon provides efficient removal of dissolved organic compounds such as waste solvents and should be considered for removal of those organic compounds not susceptible to biological oxidation. Wastewaters from chemical/pharmaceutical manufacturing are likely to contain significant quantities of such biologically refractory solvents and other organic compounds. In such cases both BOD (biochemical oxygen demand) and COD (chemical oxygen demand) should be used as measures of wastewater pollution and of removal efficienty of a wastewater treatment process. Activated carbon absorption should be considered for lowering wastewater COD if secondary biological treatment does not do this sufficiently. BOD is a measure of concentration of pollutants that can be oxidized by biological processes whereas COD is measured in terms of the amount of pollutants that can be oxidized by a strong chemical oxidizing agent. The COD value of a waste water is generally considerably larger than the BOD value. The major reason is that COD includes the effects of the biologically refractory pollutants.

[66/] Janssen Pharmaceutical Company, Beerse, Belgium. Unpublished data, 1985.

Table 13. Hungarian regulation of solvents discharged to the sewage system, maximum pollution loads and penalties for infringement

Number	Type of pollutant	Maximum pollution load (mg/liter)	Penalty (US$/liter)[a]
1.	Oils, aromatic oils, grease (extracts of organic solvents)	60	0.44
2.	Benzene	1	11.06
3.	Carbon disulfide	2	1.10
4.	Organic solvents insoluble in water	2	1.10

[a] Hungarian Forint converted to US$ on the 1983 average exchange rate of Forint 45.193 = US$ 1.00. Monthly Bulletin of Statistics, United Nations. ST/ESA/STAT/SERQ/159, March 1986.

Source: Hungarian Legislation on Water Pollution Control. Communication in 1983.

5. CONTROL TECHNOLOGY FOR AIR EMISSIONS

5.1 Introduction

Solvent reclamation is viewed by industry as a form of control technology in itself. For industries where solvent vapors are emitted, such as in the pharmaceutical industry, reclaiming of solvent vapors provides a means of emission control while recovering a valuable production material. In this case the cost of control technology is defrayed by the value of recovered solvent. Reclamation of liquid waste solvents is also a form of control technology since their disposal rather than reuse would cause additional emissions to the atmosphere.

Control technology is described below for three areas of solvent reclaiming operations: storage and handling, distillation, and disposal through incineration. The number of pharmaceuticals plants that employ control technology is not known.

5.2 Storage and handling

Hydrocarbon emissions from the storage of solvents are reduced by improved storage tank design. Floating-roof tanks emit 94 per cent to 98 per cent less hydrocarbons by weight, as compared to fixed-roof designs, by reducing the available surface area of stored solvent exposed to air and by eliminating vapor space between the solvent surface and storage tank roof. Reduction of hydrocarbon emissions by a floating-roof tank is dependent upon solvent evaporation rate, ambient temperature, loading rate, and tank capacity.[67/]

Control technology may be added to fixed-roof tanks to reduce hydrocarbon emissions from stored solvents. Tanks are refrigerated to reduce emissions by decreasing the evaporation rate of the stored solvent. Conservation vents are also used to control emissions from stored solvent. These vents are equipped with breather valves designed to prevent either the inflow of air or the

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[67/] United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratory, Cincinnati, Ohio, USA, April 1978. p. 34.

escape of vapors from the tank until some preset vacuum or pressure develops. This system prevents stored solvent from contact with the atmosphere unless the tank is being filled or drained of solvent.

Submerged filling of storage tanks and tank cars, rather than splash filling, can reduce solvent emissions by more than half. Submerged filling minimizes agitation and atomization of liquid solvent when it is pumped into the tank.

The importance of careful plant maintenance and loading procedures cannot be overemphasized. These reduce solvent emissions from leaks and spills. Fugitive emissions from process equipment leaks pose a problem not only as air pollutants but also as a safety hazard, especially when reclaiming flammable solvents. Even explosions could occur. Leaks can be controlled by replacing worn-out equipment and performing regular maintenance procedures. Careful loading procedures can reduce the number of solvent spills and consequent emissions from spilled solvent evaporaton.

5.3 Distillation

Solvent vapors vented during distillation are controlled by scrubbers and additional condensers. A countercurrent packed scrubber has been used to control vent gases from solvent distillation. In this type of unit vent gases enter from the bottom and travel up through the scrubber, which is filled with packing material. An absorbing liquid enters the scrubber from the top and passes through concurrently to the flow of vent gases. Contact between absorbing liquid and vent gases occurs in the packed section of the scrubber. Gases not absorbed by the liquid are released to the atmosphere from the top of the scrubber. One private contractor reclaiming waste solvents reported a 99 per cent contol efficiency for a gas scrubber installed in line with condenser vents.[68/]

[68/] United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratory, Cincinnati, Ohio, USA, April 1978. p. 34.

Solvent vapors vented by the condenser during distillation are also reduced by addition of a secondary condenser in series with the first. Vent gases are condensed in the secondary condenser to yield distilled solvent which had passed through the primary condenser.

5.4 Disposal through incineration

Afterburners can be used to control noncondensables and solvent vapors not condensed during distillation. Two types of afterburners used to control solvent vapors are direct flame and catalytic. The time necessary for complete combustion of solvent vapors by an afterburner will depend on the flammability of the solvent. For most solvents 0.3 s to 0.6 s at 1,193°C to 1,306°C is required for effective control of vent gases. Condenser emissions have also been controlled with the afterburner principle by venting gases to a boiler firebox where they are combusted.

Control of vent gases in the manufacture of vegetable oils has been accomplished by refrigerated condenser vents or the addition of vapor control devices utilizing carbon adsorption or oil adsorption.

In wet scrubbers, which are used to remove particulates from incinerator exhaust gases, gas flow is constricted by a venturi throat where water is atomized to remove particulates by impaction. Submicron particulates are not effectively controlled by wet scrubbers. One plant reclaiming wastes solvents reported metal oxide emissions from their incinerator stack after gas stream scrubbing.

Source severity for a representative plant with control equipment is shown in Table 14.[69]

69/ United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratory, Cincinnati, Ohio, USA, April 1978. p. 34.

Table 14. Source severities for reclaiming plants with and without control equipment[a]

Control equipment used	Source severity[b]
None	0.31
Submerged loading	0.22
Floating-roof storage tanks	0.23
Vent gas scrubber	0.12
Floating-roof storage tank and vent gas scrubber	0.082

[a] Data from a representative plant and control equipment efficiencies were used to calculate source severity.

[b] All source severities refer to total hydrocarbons emitted from a representative plant. Calculation of these source severities is the same as that used in Tables A-2 and A-3. Values shown represent the source severity for total hydrocarbons when various control equipment is utilized.

Source: Source Assessment: Reclaiming of Waste Solvents, State of the Art. US Environmental Protection Agency, April 1978.

6. FUTURE CONSIDERATIONS

Due to the increase in the price of virgin solvent, industry will strive for increased efficiencies when reclaiming solvents. Operations reclaiming up to 4.5×10^6 tons/year of solvent must achieve recovery efficiencies of greater than 90 per cent if capital losses due to solvent losses are to be avoided.[70/] Improved efficiency of recovery operations stimulated by the higher costs of solvents will serve as a self-regulating means of emission reduction. Also, national emission standards for hydrocarbons and other solvents will become increasingly stringent throughout the world.

The cost of disposal for waste from solvent reclaiming has more than doubled in the past 5 years.[71/] This has been caused by the increasing scarcity of acceptable landfill sites and the imposition of emission regulations on the disposal of liquid wastes by incineration. As an alternative to disposal, new applications for reclaimed solvent wastes are being tried. One application is improved design of incineration, so the waste solvents can serve as a heat source. Another possible application is the use of reclaimed wastes as asphalt extenders and concrete block fillers. The main application will continue to be recovery and use within the pharmaceutical plant itself, either in production processes or in equipment cleaning and other lower grade applications.

[70/] Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 18. John Wiley and Sons, Inc., New York, New York, USA, 1969, pp. 549-563.

[71/] United States Environmental Protection Agency. Source Assessment: Reclaiming of Waste Solvents, State of the Art. Industrial Environmental Research Laboratory, Cincinnati, Ohio, USA, April 1978. p. 37.

Appendix A. CALCULATION OF AIR EMISSIONS FROM SOLVENT RECLAIMING

The theory of calculation of industrial air pollution and its applicability to pharmaceutical plants. These calculations are normally not available and hence are presented in this appendix.

1. Overall air emissions from solvent reclaiming

Air emission data for a representative solvent reclaiming plant are shown in Table A-1.[72] The quantities of pollutants emitted are given, as well as the sources and heights from which the pollutants are emitted. An analysis of the severity of such emissions at ground level is given in the sections 3 and 4.

2. Definitions of pollutant concentrations[73]

Maximum ground level concentration

The maximum ground level concentration, x_{max}, for materials emitted by solvent reclamation is estimated in this appendix by Gaussian plume dispersion theory.

Time-averaged maximum ground level concentration

The maximum ground level concentration averaged over a given period of time, $\bar{x}_{max}$, is calculated from x_{max} by the following equation:

$$\bar{x}_{max} = x_{max}\left(\frac{t_o}{t}\right)^{0.17}$$

where t = averaging time, min.

t_o = short-term averaging time, $\leq$ 3 min.

The averaging times used for particulates and hydrocarbons are 24 hours and 3 hours, respectively.

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[72] Ibid, p. 30.

[73] Ibid, p. 31.

Table A-1. Summary of air emissions and related data for a representative solvent recovery plant

Parameter	Value for representative plant
Process	Solvent reclaiming
Raw material	Waste solvent
Population density, persons/km^2	653 ± 33%
Production capacity, metric tons/yr	1,737 ± 30%
Emission heights, m	
Storage tank vent	9.2 ± 17%
Condenser vent	6.4 ± 41%
Incinerator stack	18.3
Fugitive emission	2.4
Emission factor, g/kg	
Storage tank vent	0.0072 ± 53%
Condenser vent	1.65 ± 84%
Incinerator stack	
Particulates	0.72 ± 84%
Hydrocarbons	0.01
Fugitive emissions	0.455

<u>Source</u>: Source Assessment: Reclaiming of Waste Solvents, State of the Art. US Environmental Protection Agency, April 1978.

3. Source severity[74]

The hazard potential of solvent reclaiming operations can be quantified by determining a source severity, S, which is defined as the ratio of the time averaged maximum ground level concentration to F, the hazard exposure level for a pollutant. The primary ambient air quality standards for hydrocarbons and particulates in the United States are taken to represent the hazard exposure level, F. The source severity is thus calculated in the following manner:

$$S = \frac{\bar{x}_{max}}{F}$$

Table A-2 gives the emission rate, maximum ground level concentration, time-averaged maximum ground level concentration and source severity of the emission points described in this section for a representative solvent reclaiming plant.

The source severity for total hydrocarbons emitted by a representative solvent reclaiming plant has also been calculated. A mean emission height of 8.6 ± 1.8 m was used with a total hydrocarbon emission rate of 0.12 g/s. Table A-3 gives the results of this calculation.

Source severities are shown in Table A-4.

4. Affected population

The population affected by a solvent reclaiming operation is determined from representative plant data. Since no source severity greater than 1.0 was determined, the population affected by a source severity greater than 0.1 was utilized. Table A-5 gives the affected population when $\bar{x}/F > 0.1$ over an area of 0.12 km^2. This affected population was obtained by calculating the area within the isopleth for $\bar{x}_{max}$.[75]

Table A-6 lists threshold limit values (TLV) for commonly reclaimed solvents. These maximum allowable concentrations in the workplace were originally published by a conference of American governmental industrial hygienists.

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[74] Ibid, p. 31.

[75] Ibid, p. 32.

Table A-2. Emission rate, x_{max}, $\bar{x}_{max}$ and source severity for emissions from a representative solvent reclaiming plant

Emission point	Emission rate, g/s	x_{max}, g/m^3	$\bar{x}_{max}$, g/m^3	Source severity
Storage tank vent	0.0004	2.5×10^{-7}	1.2×10^{-7}	0.00075
Condenser	0.09	1.1×10^{-4}	5.5×10^{-5}	0.34
Incinerator stack				
Particulates	0.04	6.3×10^{-6}	2.2×10^{-6}	0.0085
Hydrocarbons	0.0005	7.8×10^{-8}	3.9×10^{-18}	0.00024
Fugitive emissions	0.03	2.7×10^{-4}	1.3×10^{-4}	0.84

Table A-3. Source severity for total hydrocarbons emitted from a representative plant (uncontrolled emissions)

Emission	Emission rate,gs	x_{max} ,g/m^3	$\bar{x}_{max}$,g/m^3	Source severity
Hydrocarbons	0.12	1.0×10^{-4}	5.0×10^{-5}	0.31

Table A-4. Source severity for selected solvents[a/]

Solvent	TLV, g/m^3	$\bar{x}_{max}$,g/m^3	Source severity
Acetone	2.4	5.0×10^{-5}	0.0063
Isopropanol	0.98	5.0×10^{-5}	0.015
Methylethylketone	0.59	5.0×10^{-5}	0.026
Toluene	0.37	5.0×10^{-5}	0.042
Butanol	0.3	5.0×10^{-5}	0.05

a/ Data for emission rate, x_{max} and $\bar{x}_{max}$ were taken from Table A-2.

Table A-5. Affected population for a representative plant (uncontrolled emissions)

Parameter	Value for representative plant
Population density, persons/km^2	653
Emission height, m	8.6
Emission rate, g/s	0.12
Pollutant type	hydrocarbons
Source severity	0.31
Affected area, km^2	0.12
Affected population, persons	78

Source (Tables A-2 to A-5): Source Assessment: Reclaiming of Waste Solvents, State of the Art. US Environmental Protection Agency, April 1978.

Table A-6. Threshold limit values for commonly reclaimed solvents

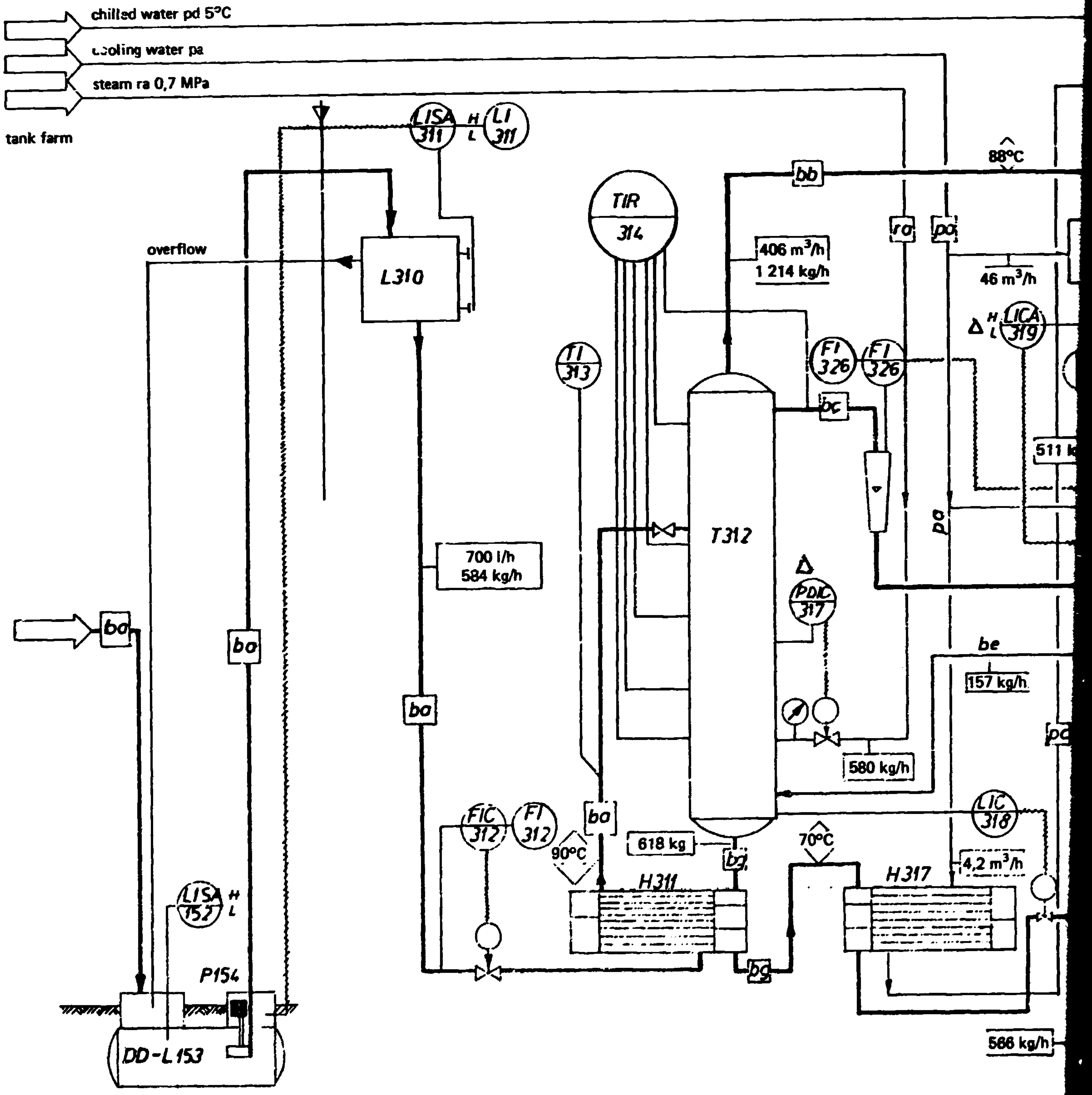
Solvent	TLV (mg/m3)
Acetone	2,400
Amylacetate	650
Benzene	80
Butanol	300
Cyclohexane	1,050
Ehtylacetate	1,400
Ethanol	1,900
Hexane	1,800
Isopropanol	980
Methylethylketone	590
Methylisobutylketone	410
Methylenechloride	360
Perchloroethylene	670
Toluene	375
1,1,1-Trichloroethane	1,900
Trichloroethylene	535
Xylene	435

Source: Source Assessment: Reclaiming of Waste Solvents, State of the Art. US Environmental Protection Agency, April 1978.

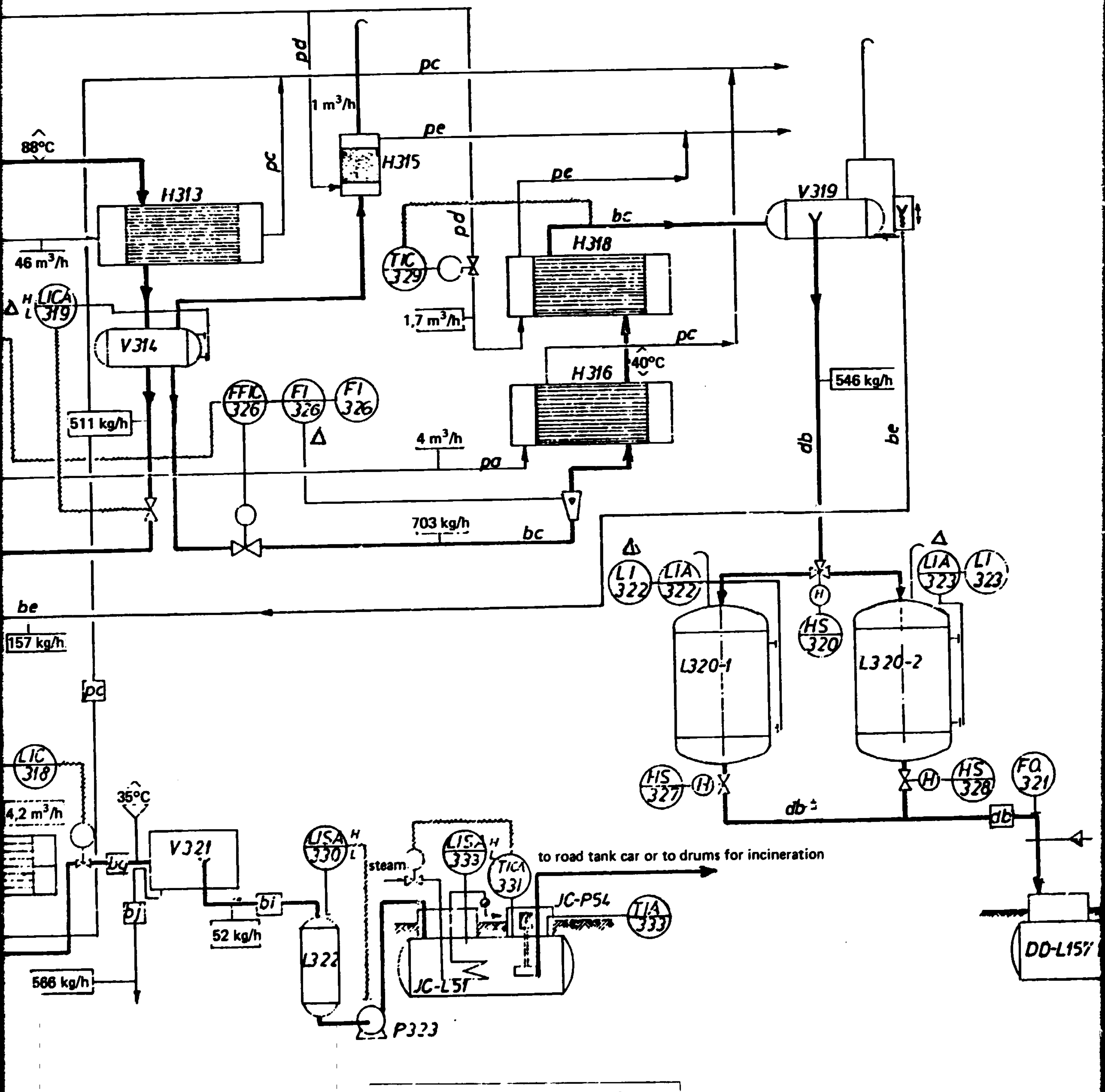
APPENDIX B. PROCESS FLOW SHEETS FOR FOUR SOLVENT RECOVERY UNITS

Following are process flow sheets showing: (1) a general scheme for a solvent recovery unit; (2) a recovery unit for methanol; (3) a recovery unit for acetone; and (4) a unit suitable for recovering either benzene, toluene, or xylene. These flow sheets are based on engineering designs prepared by the Vegyterv Engineering Company, Budapest, Hungary for various Hungarian pharmaceutical companies.

The flow sheets should be useful for developing countries because they are all based on standard equipment available internationally for use in chemical process industries. Thus the flow sheets can aid developing country engineers in preparing tenders for outside bidding for construction of solvent recovery units in their countries.


chilled water pd 5°C
cooling water pa
steam ra 0,7 MPa
tank farm
LISA 311
H
L
LI 311
88°C
overflow
L310
TIR 314
bb
ra
pa
406 m³/h
1 214 kg/h
46 m³/h
Δ
H
L
LICA 319
FI 313
FI 326
FI 326
bc
511 k
T312
pa
700 l/h
584 kg/h
Δ
PDIC 317
bo
bo
ba
be
157 kg/h
pa
580 kg/h
ba
LIC 318
FIC 312
FI 312
90°C
618 kg
bg
70°C
4,2 m³/h
H311
H317
LISA 152
H
L
P154
bg
DD-L153
586 kg/h

SECTION 1


pd
pc
1 m³/h
pe
H315
88°C
H313
pc
46 m³/h
LICA 319
H
L
V314
511 kg/h
pe
bc
H318
TIC 329
pd
1,7 m³/h
pc
40°C
H316
FFIC 326
FI 326
FI 326
4 m³/h
pa
703 kg/h
bc
V319
546 kg/h
db
be
be
157 kg/h
LI 322
LIA 322
LIA 323
LI 323
HS 320
L320-1
L320-2
HS 327
HS 328
FQ 321
db
db
pc
LIC 318
4,2 m³/h
35°C
V321
bi
bi
52 kg/h
566 kg/h
LISA 330
H
L
L322
P323
steam
LISA 333
H
L
TICA 331
JC-P54
TIA 333
JC-L51
to road tank car or to drums for incineration
DD-L157

SECTION 2

SOLVENT REGENERATION PROCESS FLOWSHEET

Instrument List

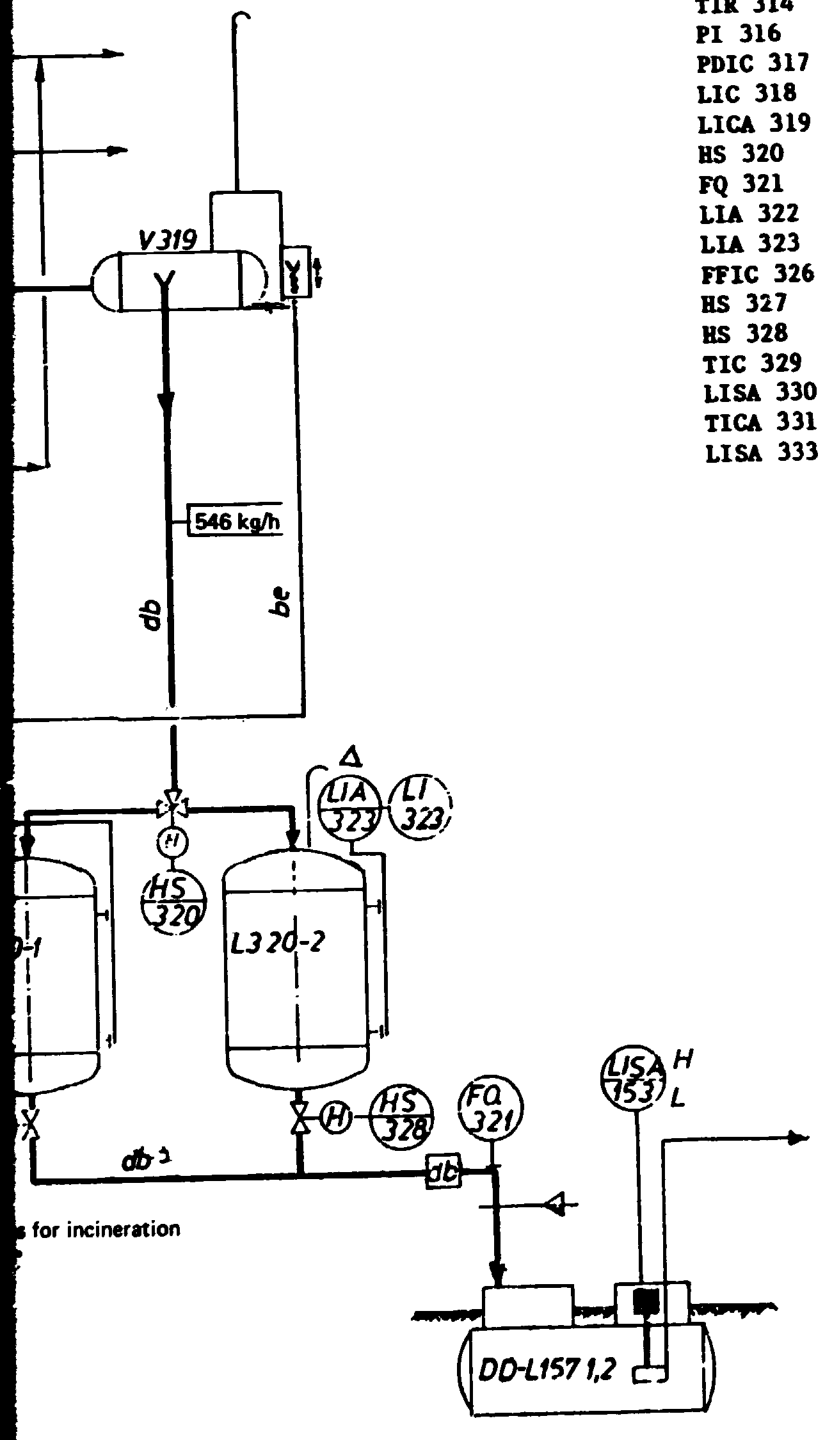
LISA 311	Level indicator and control with alarm
FIC 312	Flow indicator and control with alarm
TI 313	Temperature indicator and control with alarm
TIR 314	Temperature indicator and control and record
PI 316	Pressure indicator
PDIC 317	Pressure differential indicator and control
LIC 318	Level indicator and control with alarm
LICA 319	Level indicator and control with alarm
HS 320	Remote-controlled valve
FQ 321	Flow counter
LIA 322	Level indicator with alarm
LIA 323	Level indicator with alarm
FFIC 326	Reflux ratio control and indicator
HS 327	Remote-controlled valve
HS 328	Remote-controlled valve
TIC 329	Temperature indicator and control
LISA 330	Level indicator, control and alarm
TICA 331	Temperature indicator, control and alarm
LISA 333	Level indicator, control and alarm

List of Flows

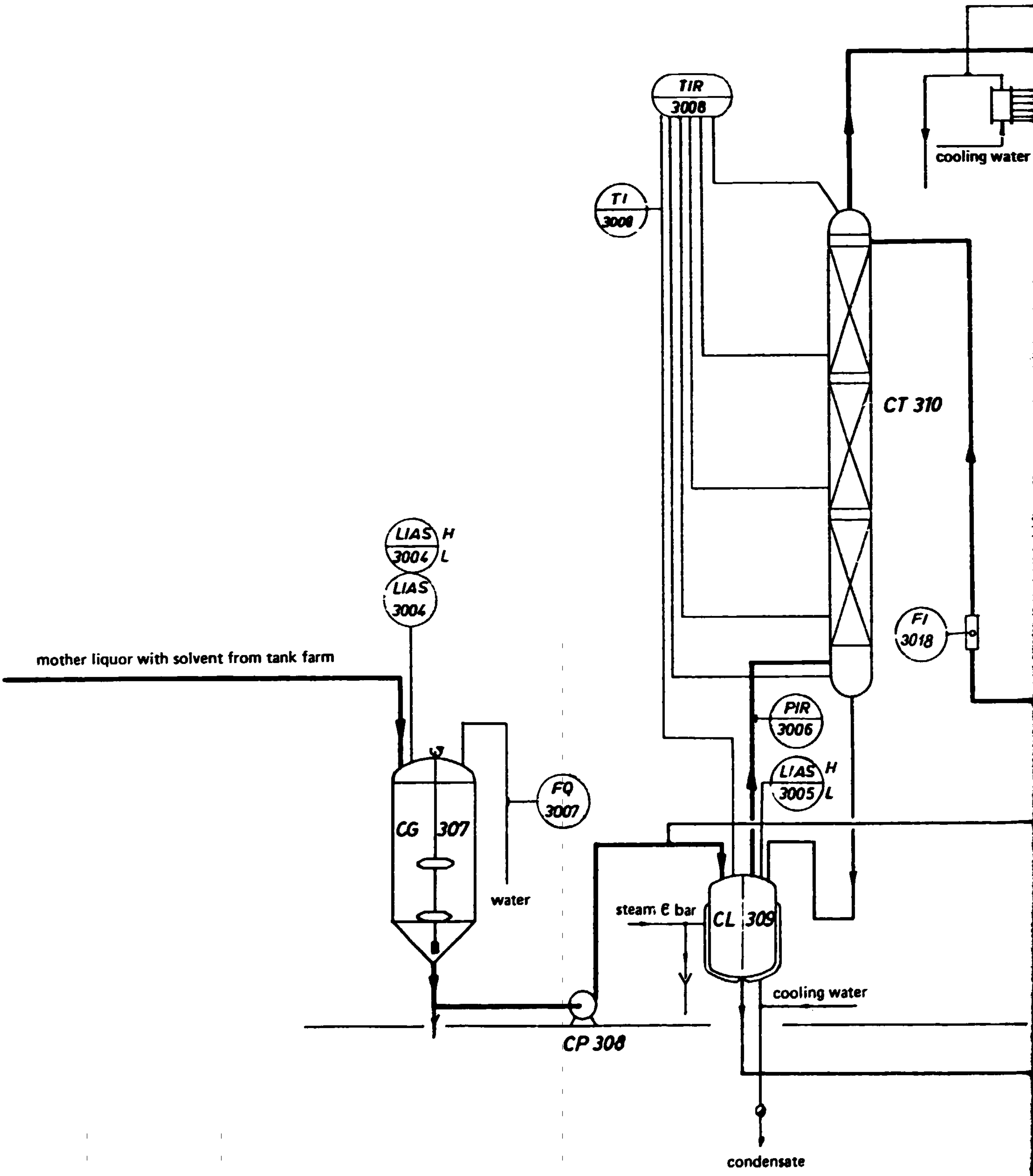
ba	isobutylacetate mother liquid
bb	vapours
bc	condensate
db	regenerated isobutylacetate
bg	bottoms
bi	oily organic phase
bj	effluent
be	water phase
pa	cooling water (fresh) 28°C
pb	well water
pc	cooling water (used) 33°C
pd	chilled water (fresh) 5°C
pe	chilled water (used) 10°C
ra	steam

Equipment List

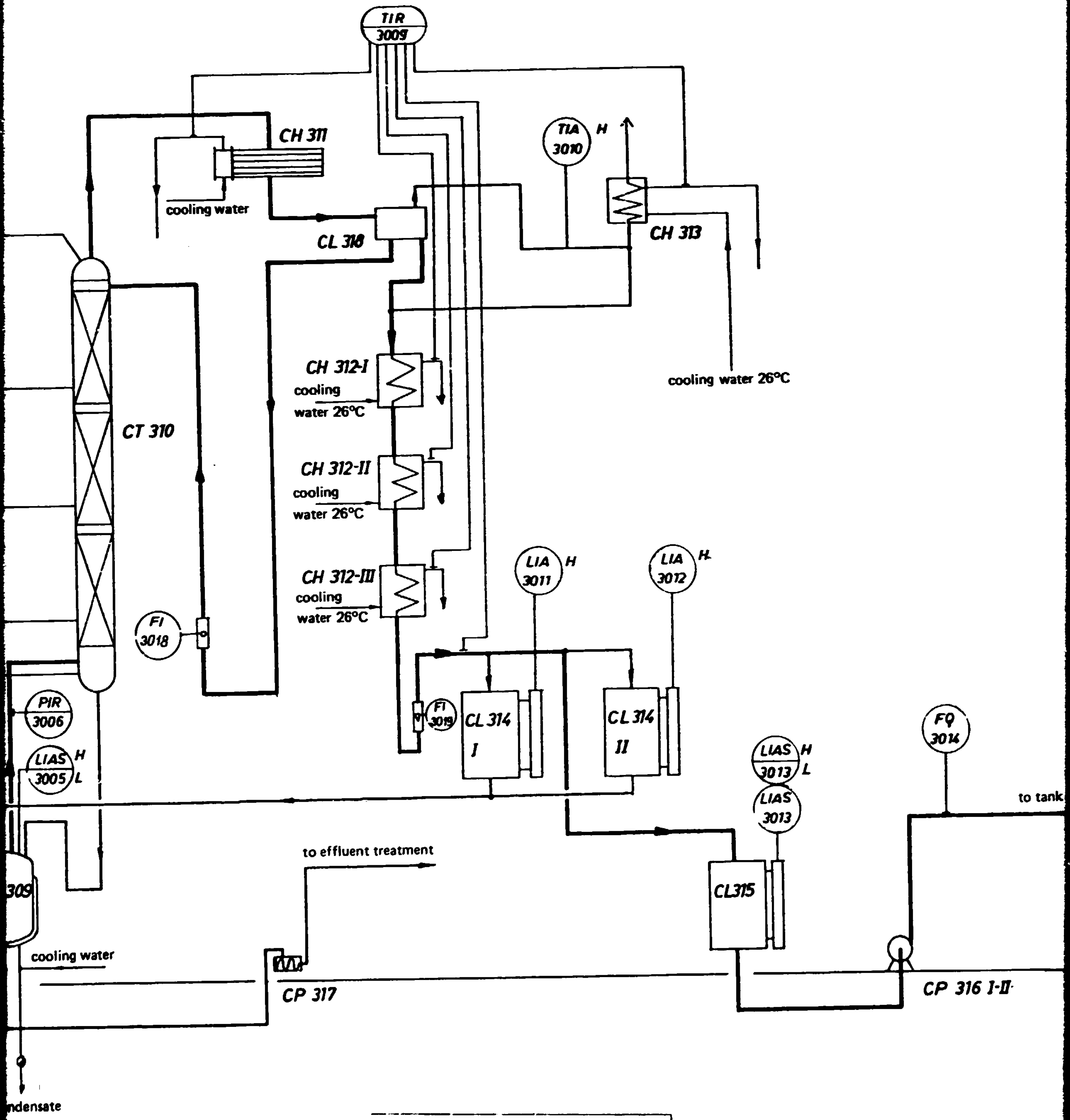
JC-L51	Collecting tank for oily phase
L310	Dosage vessel
H311	Acetone preheater
T312	Distillation tower
T313	Condensator for isobutylacetate
V314	Reflux vessel
H315	Vapour cooler
H316	Distillate cooler
H317	Bottom product end cooler
H318	End cooler
V319	Separation vessel
L320	Collecting vessel
V321	Separation vessel
L322	Collecting vessel
P323	Pump
JC-P54	Pump



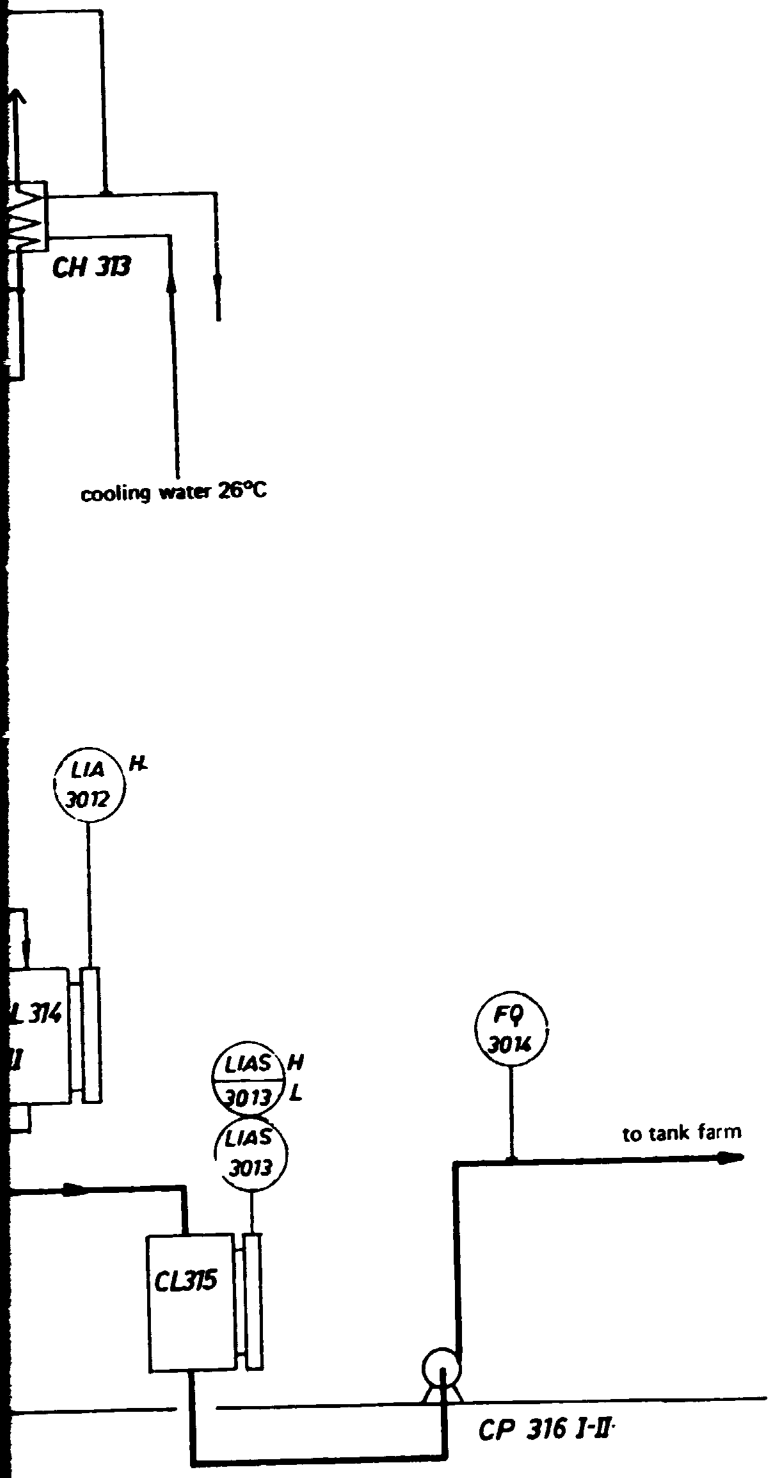
SECTION 3


TIR
3008
TI
3008
cooling water
CT 310
FI
3018
LIAS H
3004 L
LIAS
3004
mother liquor with solvent from tank farm
PIR
3006
LIAS H
3005 L
FQ
3007
CG 307
water
steam 6 bar
CL 309
cooling water
CP 308
condensate

SECTION 1


TIR 3009
CH 311
cooling water
CL 318
TIA 3010 H
CH 313
cooling water 26°C
CT 310
CH 312-I
cooling water 26°C
CH 312-II
cooling water 26°C
CH 312-III
cooling water 26°C
FI 3018
LIA 3011 H
LIA 3012 H
FI 3019
CL 314 I
CL 314 II
PIR 3006
LIAS 3005 H L
LIAS 3013 H L
LIAS 3013
FQ 3014
to tank
to effluent treatment
309
CL315
cooling water
CP 317
CP 316 I-II
ndensate

SECTION 2



REGENERATION OF BENZENE, TOLUENE AND XYLENES

Equipment List

CG 307	Mixer
CP 308	Pump
CL 309	Reboiler
CT 310	Distillation tower
CH 311	Condenser
CH 312 I-III	Vapour cooler
CH 313	Vapour cooler
CL 314 I-II	Collector
CL 315	Collector
CP 316 I-II	Pump
CP 317	Pump
CL 318	Reflux distributor

Instrument List

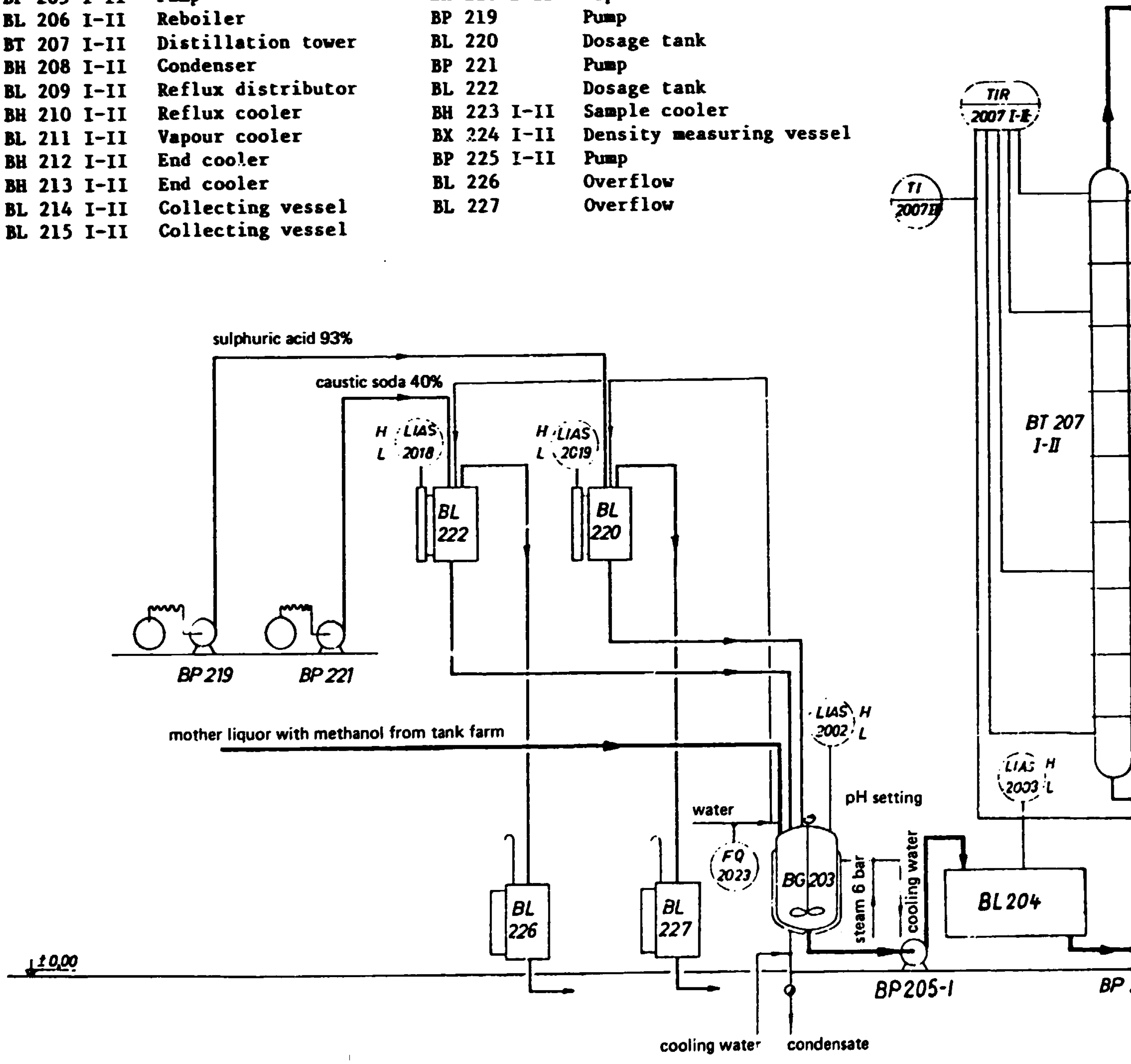
LIAS 3004	Level indicator alarm
LIAS 3005	Level indicator alarm
PIR 3006	Pressure recorder
FQ 3007	Flow indicator and summing
TIR 3008	Temperature indicator recorder
TIR 3009	Temperature indicator recorder
TIA 3010	Temperature indicator, max.
LIA 3011	Level indicator alarm
LIA 3012	Level indicator alarm
LIAS 3013	Level indicator alarm
FQ 3014	Flow indicator and summing
TIA 3015	Temperature indicator, min.-max.
FI 3018	Flow indicator
FI 3019	Flow indicator

SECTION 3

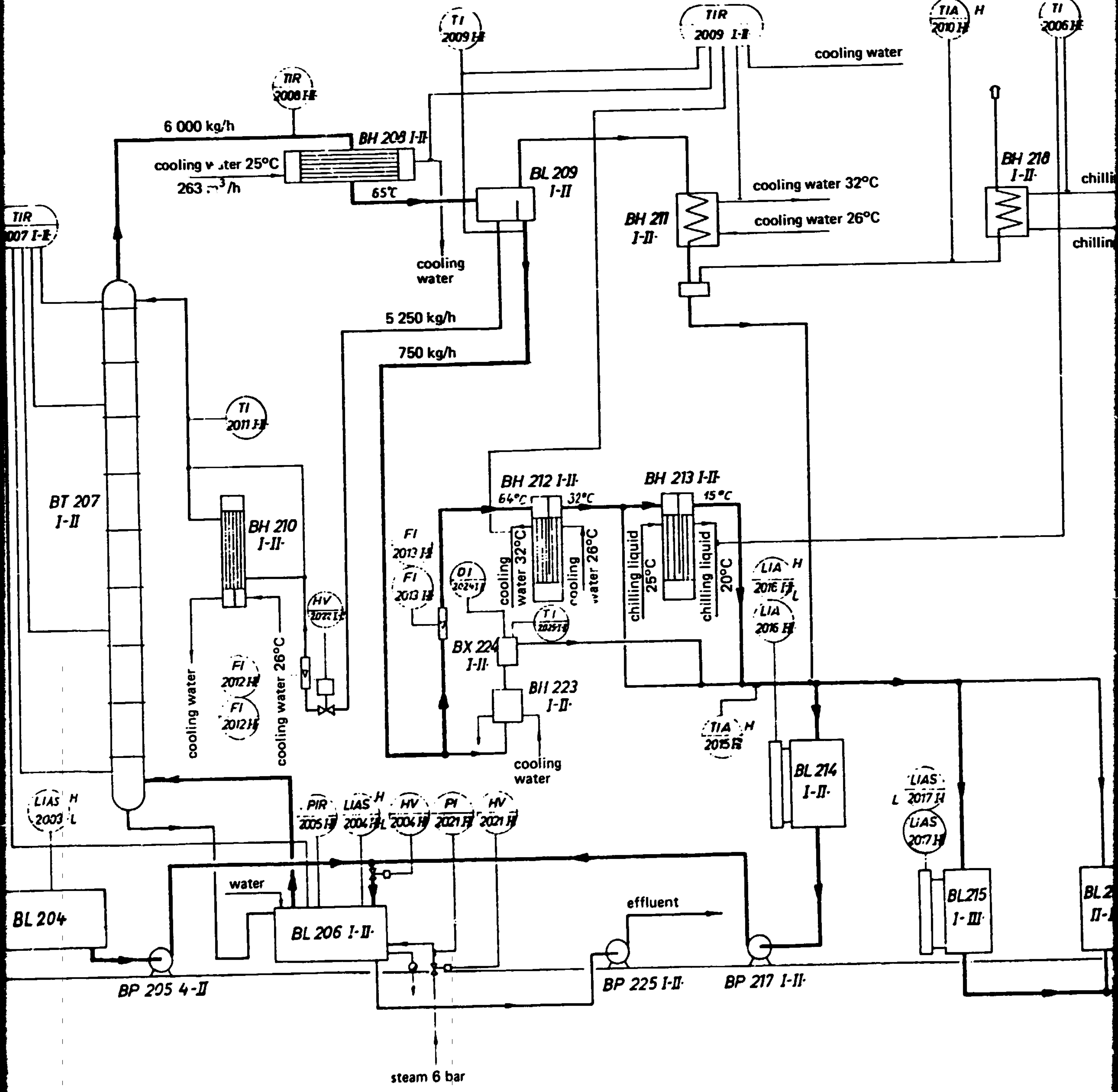
METHANOL REGENERATION PROCESS FLOWSHEET

Equipment List

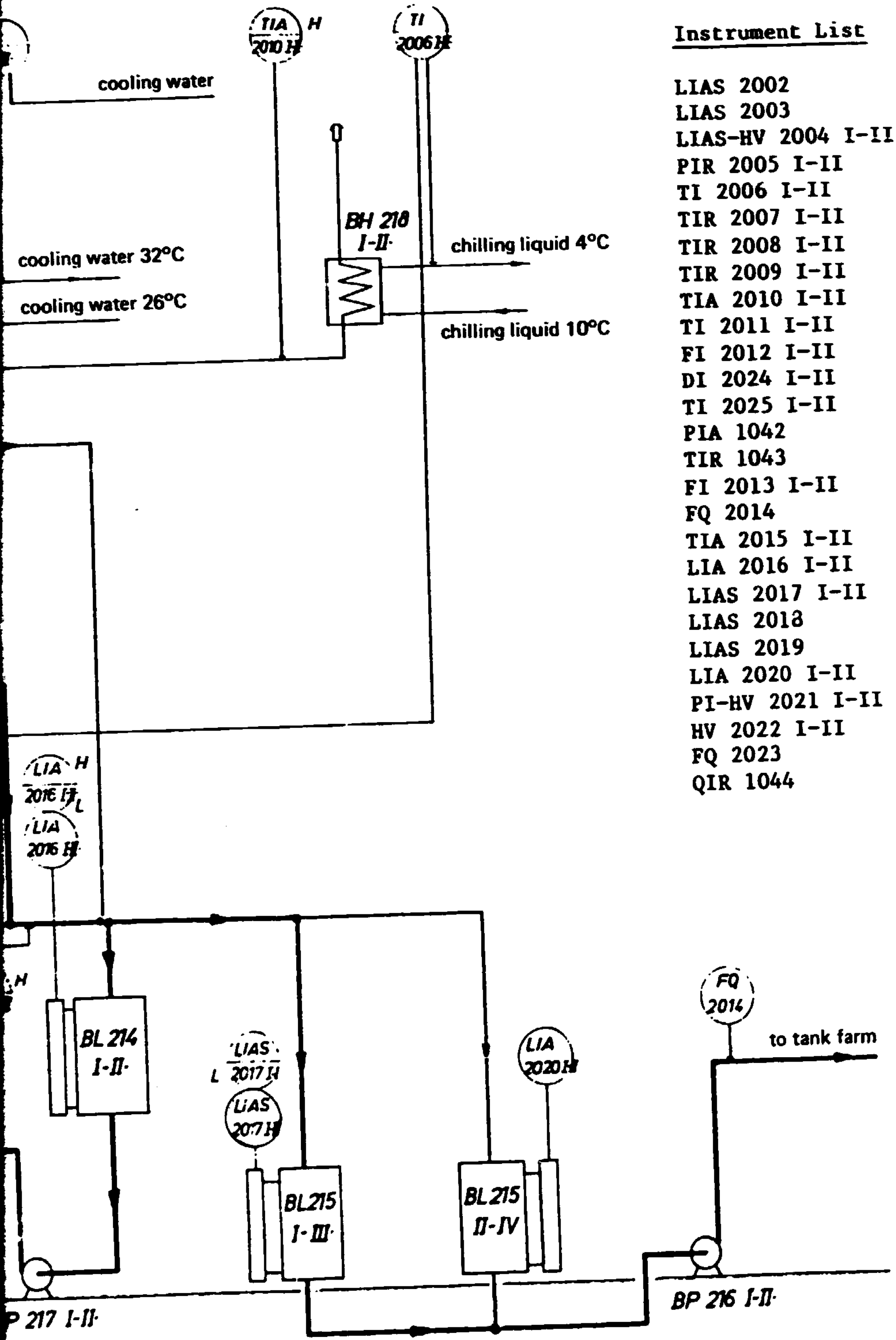
BG 203	Mixer for pH setting
BL 204	Intermediate vessel
BP 205 I-II	Pump
BL 206 I-II	Reboiler
BT 207 I-II	Distillation tower
BH 208 I-II	Condenser
BL 209 I-II	Reflux distributor
BH 210 I-II	Reflux cooler
BL 211 I-II	Vapour cooler
BH 212 I-II	End cooler
BH 213 I-II	End cooler
BL 214 I-II	Collecting vessel
BL 215 I-II	Collecting vessel
BP 216 I-II	Pump
BP 217 I-II	Pump
BH 218 I-II	Vapour cooler
BP 219	Pump
BL 220	Dosage tank
BP 221	Pump
BL 222	Dosage tank
BH 223 I-II	Sample cooler
BX 224 I-II	Density measuring vessel
BP 225 I-II	Pump
BL 226	Overflow
BL 227	Overflow



SECTION 1


TI 2009 I-II
TIR 2009 I-II
cooling water
TIA 2010 I-II H
TI 2006 I-II
TIR 2008 I-II
6 000 kg/h
BH 208 I-II
cooling water 25°C
263 m³/h
65°C
BL 209 I-II
cooling water 32°C
cooling water 26°C
BH 211 I-II
BH 218 I-II
chilli
chillin
TIR 2007 I-II
cooling water
5 250 kg/h
750 kg/h
TI 2011 I-II
BT 207 I-II
BH 210 I-II
HV 2022 I-II
FI 2012 I-II
cooling water
cooling water 26°C
BH 212 I-II
64°C
32°C
BH 213 I-II
15°C
FI 2013 I-II
QI 2024 I-II
cooling water 32°C
cooling water 26°C
chilling liquid 25°C
chilling liquid 20°C
TI 2025 I-II
BX 224 I-II
BH 223 I-II
cooling water
LIA 2016 I-II H L
TIA 2015 I-II H
BL 214 I-II
LIAS 2003 H L
PIR 2005 I-II
LIAS 2004 I-II H L
HV 2004 I-II
PI 2021 I-II
HV 2021 I-II
LIAS 2017 I-II H L
BL 215 I-III
BL 2
II-I
water
BL 204
BL 206 I-II
effluent
BP 205 I-II
BP 225 I-II
BP 217 I-II
steam 6 bar

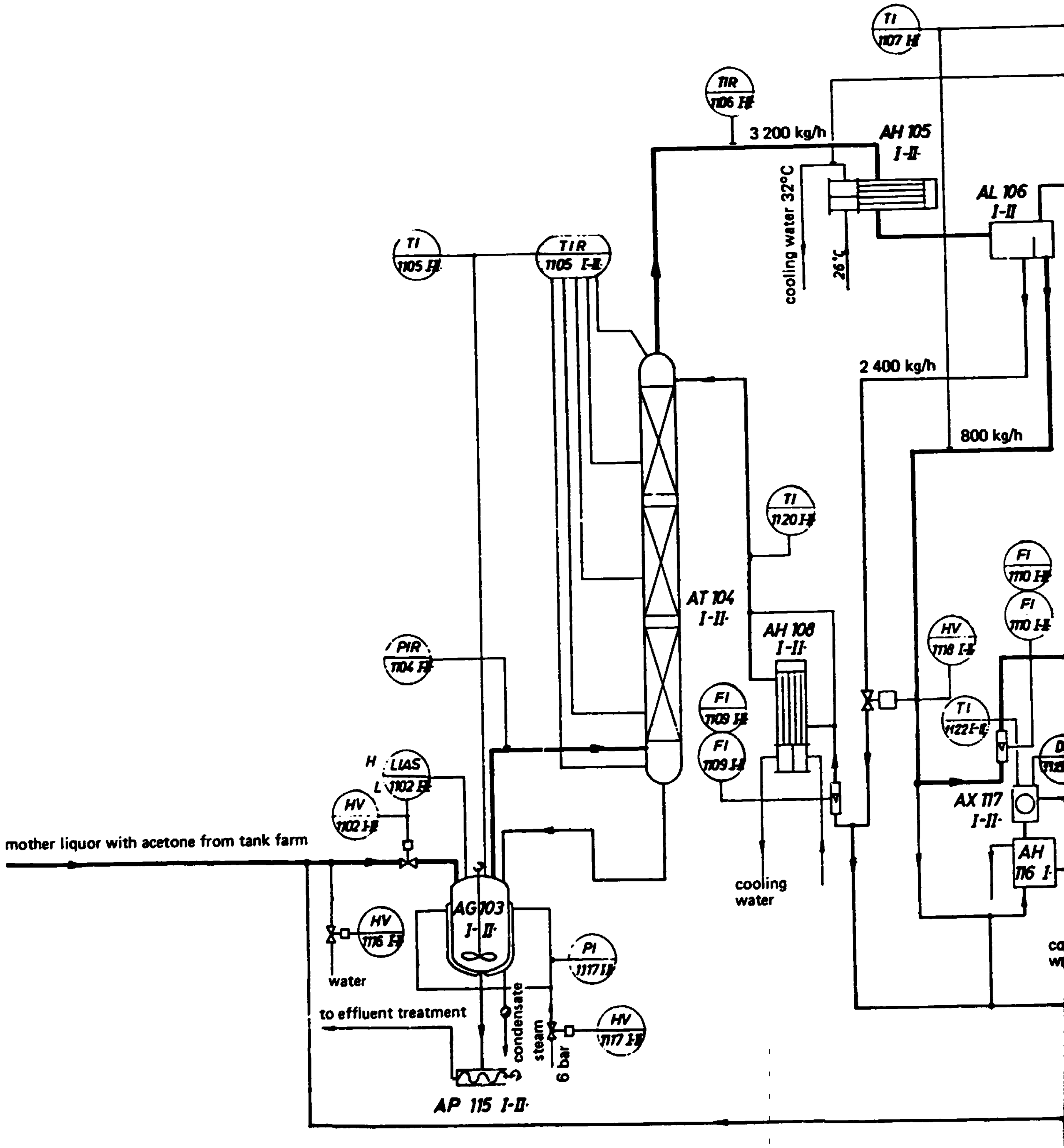
SECTION 2



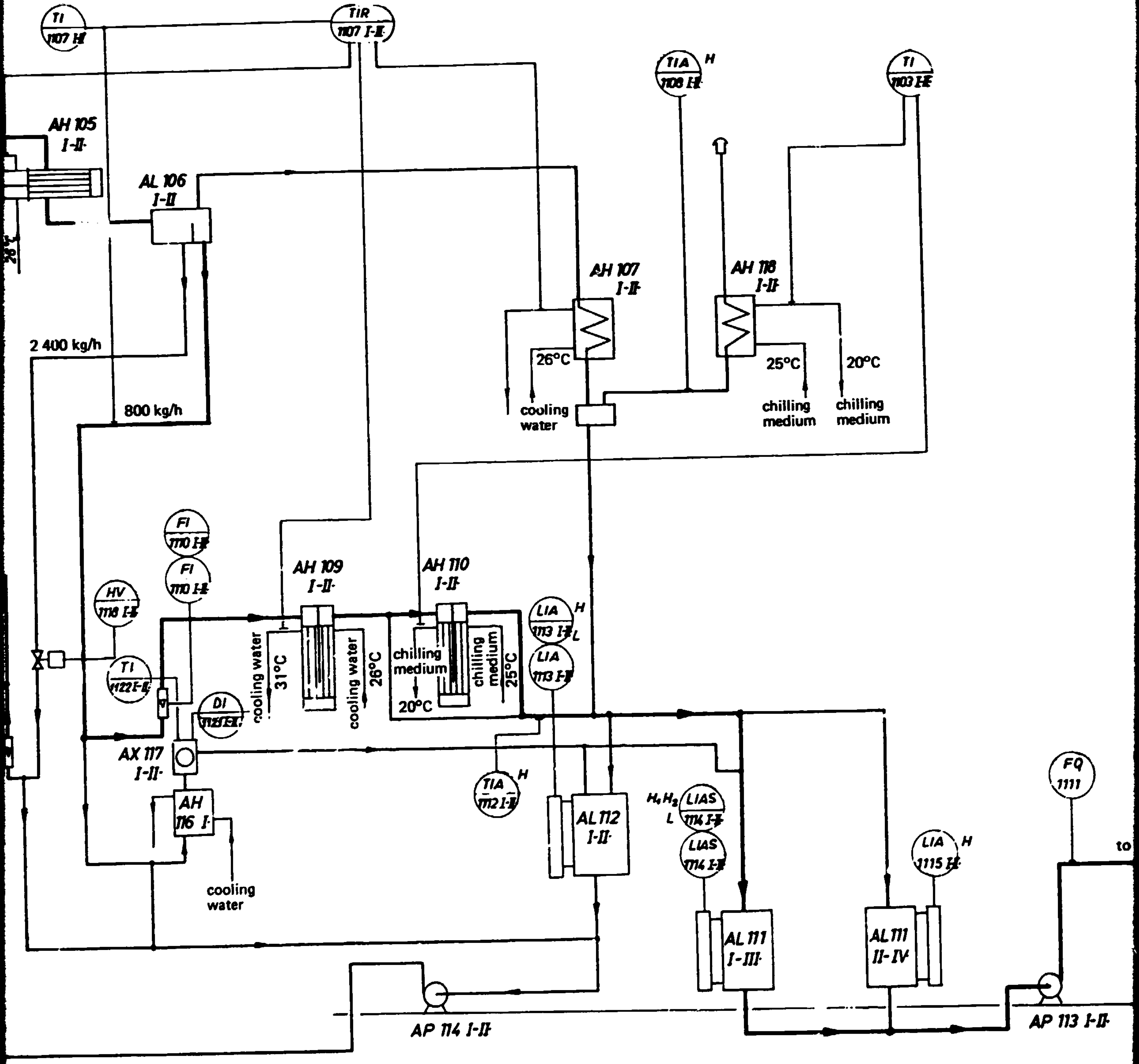
Instrument List

LIAS 2002	Level indicator alarm
LIAS 2003	Level indicator alarm
LIAS-HV 2004 I-II	Level indicator alarm
PIR 2005 I-II	Pressure recorder
TI 2006 I-II	Temperature indicator
TIR 2007 I-II	Temperature indicator recorder
TIR 2008 I-II	Temperature indicator recorder
TIR 2009 I-II	Temperature indicator recorder
TIA 2010 I-II	Temperature indicator alarm
TI 2011 I-II	Temperature indicator alarm
FI 2012 I-II	Flow indicator
DI 2024 I-II	Density indicator
TI 2025 I-II	Temperature indicator
PIA 1042	Pressure indicator alarm
TIR 1043	Temperature indicator recorder
FI 2013 I-II	Flow indicator
FQ 2014	Flow indicator and summing
TIA 2015 I-II	Temperature indicator, max.
LIA 2016 I-II	Level indicator, min.-max.
LIAS 2017 I-II	Level indicator, min.-max. I-II
LIAS 2018	Level indicator, min.-max.
LIAS 2019	Level indicator, min.-max.
LIA 2020 I-II	Level indicator, min.-max.
PI-HV 2021 I-II	Pressure indicator and controller
HV 2022 I-II	Flow controller
FQ 2023	Flow indicator and summing
QIR 1044	Flow indicator and summing

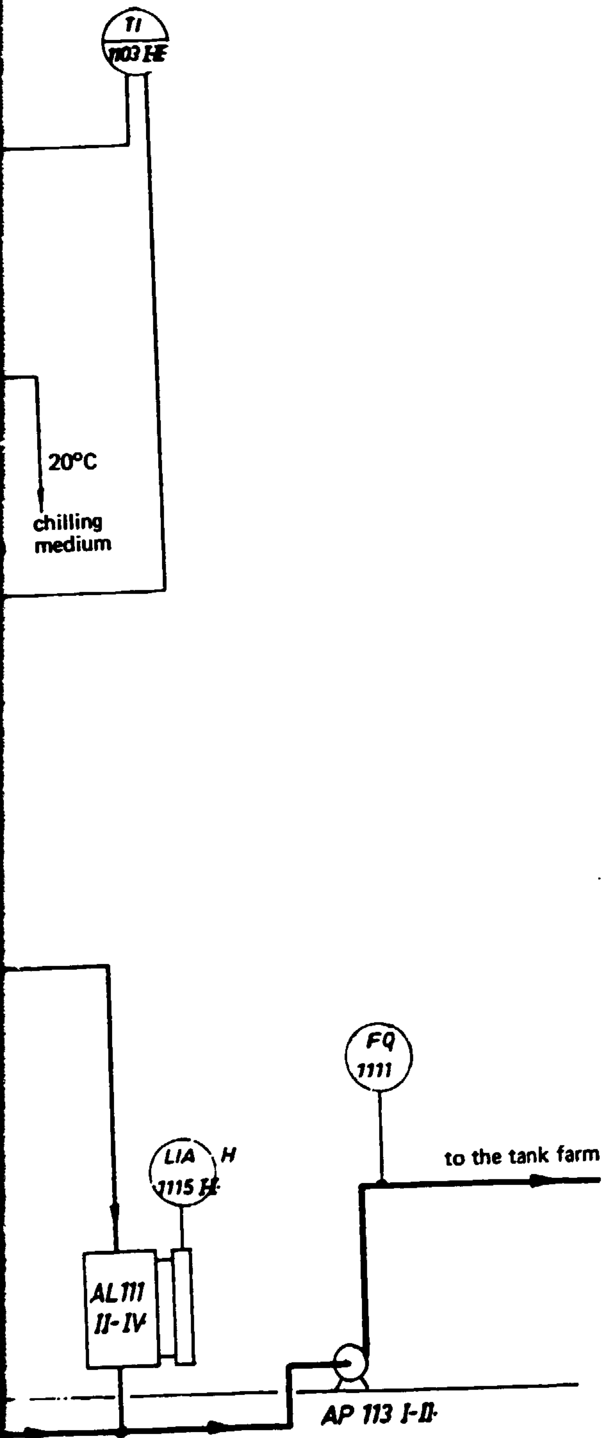
SECTION 3


TI 1107 I-II
TIR 1106 I-II
3 200 kg/h
AH 105 I-II
cooling water 32°C
26°C
AL 106 I-II
TI 1105 I-II
TIR 1105 I-II
2 400 kg/h
800 kg/h
TI 1120 I-II
AT 104 I-II
AH 108 I-II
FI 1110 I-II
FI 1110 I-II
HV 1118 I-II
TI 1122 I-II
PIR 1104 I-II
FI 1109 I-II
FI 1109 I-II
H
LIAS 1102 I-II
L
HV 1102 I-II
AX 117 I-II
AH 116 I-
mother liquor with acetone from tank farm
cooling water
AG 103 I-II
HV 1116 I-II
PI 1117 I-II
water
to effluent treatment
condensate
steam 6 bar
HV 1117 I-II
AP 115 I-II

SECTION 1


TI 1107 H
TIR 1107 I-II
TIA 1108 H H
TI 1103 I-II
AH 105 I-II
AL 106 I-II
28°C
2 400 kg/h
800 kg/h
AH 107 I-II
AH 118 I-II
26°C
cooling water
25°C
20°C
chilling medium
chilling medium
FI 1110 I-II
FI 1110 I-II
HV 1118 I-II
TI 1122 I-II
DI 1123 I-II
AH 109 I-II
cooling water
31°C
cooling water
26°C
AH 110 I-II
chilling medium
20°C
chilling medium
25°C
LIA 1113 I-II H L
LIA 1113 I-II
AX 117 I-II
AH 116 I
cooling water
TIA 1112 I-II H
AL 112 I-II
H, H2 LIAS 1114 I-II L
LIAS 1114 I-II
AL 111 I-III
LIA 1115 H H
AL 111 II-IV
FQ 1111
to
AP 114 I-II
AP 113 I-II

SECTION 2



REGENERATION OF ACETONE

Equipment List

AG 103 I-II	Reboiler with mixer
AT 104 I-II	Distillation tower
AH 105 I-II	Condenser
AL 106 I-II	Reflux distributor
AH 107 I-II	Vapour cooler
AH 108 I-II	Reflux cooler
AH 109 I-II	End cooler
AH 110 I-II	End cooler
AL 111 I-IV	Collector
AL 112 I-II	Collector
AP 113 I-II	Pump
AP 114 I-II	Pump
AP 115 I-II	Pump
AH 116 I-II	Sample cooler
AX 117 I-II	Density measuring vessel
AH 118 I-II	Vapour cooler

Instrument List

LIAS HV 1102 I-II	Level indicator, min.-max.
TI 1103 I-II	Temperature indicator
PIR 1104 I-II	Pressure recorder
TIR 1105 I-II	Temperature indicator recorder
TIR 1106 I-II	Temperature indicator recorder
TIR 1107 I-II	Temperature indicator recorder
TIA 1108 I-II	Temperature indicator alarm
FI 1109 I-II	Flow indicator
FI 1110 I-II	Flow indicator
FQ 1111	Flow indicator and summing
TIA 1112 I-II	Temperature indicator alarm
LIA 1113 I-II	Level indicator, min.-max.
LIAS 1114 I-II	Level indicator, min.-max. I-II
LIA 1115 I-II	Level indicator, max.
HV 1116 I-II	Flow controller
PI-HV 1117 I-II	Pressure indicator and controller
HV 1118 I-II	Flow controller
PIA 1119	Pressure indicator
TI 1120 I-II	Temperature indicator
DI 1121 I-II	Density indicator
TI 1122 I-II	Temperature indicator
PIA 1123 I-II	Pressure indicator alarm

SECTION 3

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SOMMAIRE

Cette étude présente une analyse technique des opérations de récupération pratiquées dans l'industrie pharmaceutique et illustre par des exemples les aspects économiques de la récupération des solvants. Elle souligne en plus les aspects particulièrement importants pour les pays en développement tels que l'économie de devises effectuée par une importation réduite de matières vierges.

A cause du coût élevé des solvants dans l'industrie pharmaceutique et de l'approvisionnement souvent difficile dans les pays en développement, le présent travail fait remarquer que la récupération de solvants usagés constitue à la fois une sage politique économique et un moyen additionnel de protéger l'environnement. Les usines de fabrication pharmaceutique peuvent souvent récupérer des solvants assez purs pour les réutiliser dans leurs procédés de fabrication. Cette opération s'effectue sur les vapeurs ou les composés liquides. Dans les cas où les solvants n'atteignent plus la qualité désirable, plusieurs moyens sont suggérés qui permettent de les utiliser dans le nettoyage de contenants ou autres fonctions d'entretien.

L'étude passe en revue les quatre types d'unités de récupération en usage dans les usines de produits pharmaceutiques: (1) stripping, (2) tour de distillation, (3) séchage de produits sous vide ou sous pression atmosphérique et (4) utilisation de carbone activé. En plus de revoir les pratiques générales d'ingénierie recommandées pour l'entreposage et la manipulation des solvants, l'étude précise aussi que dans les pays tropicaux en développement, l'entreposage devra se faire de préférence dans des cuves sous-terraines ou encore dans des récipients munis de dispositifs d'arrosage constant. Les contenants ne devront pas être remplis à capacité pour permettre l'augmentation de volume produite par la chaleur et pour éviter ainsi les dangers d'explosion.

EXTRACTO

El estudio realiza un análisis técnico para operaciones de recuperación de solventes en la industria farmacéutica y presenta ejemplos de los aspectos económicos. Se da especial importancia a la recuperación de solventes especialmente importantes para países en vías de desarrollo, como ser ahorro en divisas por ser menores las necesidades de importación de solventes vírgenes.

Ya que solventes para la industria farmacéutica son caros y difícil de conseguir en muchos países en vías de desarrollo, el estudio señala que la recuperación de solventes usados es una política sensata además de protejer el medio ambiente. Las plantas para la elaboración de productos farmacéuticos pueden, a menudo, recuperar los solventes suficientemente puros para utilizarlos nuevamente en procesos de elaboración. La recuperación puede ser a partir de vapores o de mezclas líquidas. Si este tipo de recuperación de solvente no es económica, el estudio demuestra muchos ejemplos de recuperación de solventes para limpieza de recipientes y otras funciones domésticas.

El estudio trata las cuatro categorías de unidades para recuperación de solventes utilizadas por empresas farmacéuticas. Estas son: (1) regeneración por destilación en la planta (stripping), (2) torres de destilación, (3) secado del producto bajo vacío o presión atmosférica, (4) uso de carbón activado. Además de buenas prácticas de ingeniería que se deben seguir para el almacenamiento y manipuleo de solventes, el estudio explica que en los países en vías de desarrollo en climas tropicales, los tanques de almacenamiento pueden ser subterráneos, o de lo contrario, deben rociarse contínuamente con agua. Los tambores no deben llenarse por completo y así permitir la expansión de los solventes con el aumento de temperatura. Todo esto reducirá en gran parte los riesgos de explosión.

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QUESTIONNAIRE

Solvent recovery and disposal of unrecoverable solvents used in the pharmaceuticals industry

	(please check appropriate box)	
	yes	no
(1) Were the data contained in the study useful?	☐	☐
(2) Was the analysis sound?	☐	☐
(3) Was the information provided new?	☐	☐
(4) Did you agree with the conclusion?	☐	☐
(5) Did you find the recommendations sound?	☐	☐
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