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Preliminary Outline for Book:

Engineering for Nuclear Reactor Fuel Reprocessing

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FOREWORD

1.0

The outline in its present form represents the state of our thinking at an arbitrary cut-off date of October 15, 1957, and makes no pretense of completeness or elegance.

2.0

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	a. HRT-CP	Fig.: Forces in Axial Flow Hydroclone
	b. HRT loops	Fig.: Efficiency of Separation vs. Pressure Drop
	c. Solvent clean-up - Thorex	Fig.: Use of Multiple Clone Systems
3.3.4 Operational problems		
	a. Backmixing	Fig.: Effect of Backmixing of Efficiency
	b. Underflow pot	Fig.: Circulation in Hydroclone Underflow Pot

3.3.5 Design considerations

a. Geometry (underflow port, vortex finder, etc.)

b. Efficiency

c. Pressure drop

3.4 ----

3.4.1 Thoria slurry dewatering - England

3.4.2 Fused salt-liquid metal systems - England

4.0 Filtration (Liquid-Solid)

4.1 Introduction

4.1.1 Scope

4.1.2 Constant pressure vs. constant rate

4.1.3 Singular characteristics of radiochemical applications

a. Difficulty of dressing remotely

b. Need for high efficiency

c. Small volume of solids, usually

d. Cake handling

e. Radiation damage

4.2 Sintered Metal or Glass

4.2.1 Description

a. Star, cone, etc. Fig.: Typical Filters for Radiochemical Use

4.2.2 Theory

a. Pore size

4.2.3 Applications

a. Dissolver solutions

(1) MTR (star filter)

(2) ICPP, original installation

(3) Redox Pilot Plant - ORNL

(4) Purex Pilot Plant - ORNL

(5) "25" Pilot Plant - ORNL

(6) "23" Pilot Plant - ORNL

b. RaLa - Idaho (metal)

c. RaLa - ORNL (glass)

4.2.4 Operational difficulties

a. Corrosion enlargement of pores

b. Plugging

4.2.5 Design considerations

a. Capacity

b. Pressure drop through septum

c. Wash water requirements

d. Blower requirements for vacuum filtration

4.3 Wire Baskets

4.3.1 Description, including size of opening

4.3.2 Applications

a. Clean-up of solvent extraction feed - ICPP (expanded)

4.4 Fiberglas

4.4.1 Description

4.4.2 Theory

4.4.3 Applications

a. Scrub streams - Redox, Thorex

b. Solvent streams - Thorex, SR

c. Solvent clean-up - SR

d. Particulate removal from interfacial crud - Thorex

4.4.4 Design considerations

a. Fiber density

b. Fiber diameters

c. Pressure drop

4.5 Rotary Drum Filter

4.5.1 Conventional equipment

a. Relative ease of shielding for alpha radiation

4.5.2 Applications

a. ThO_2 preparation - ORNL

b. KAPL wastes

4.5.3 Design considerations

a. Alpha containment

b. Compare 4.2.5

4.6 Magnetic Filter

4.6.1 Description — Fig.: Photograph of Installed Magnetic Filter

a. Electromagnet

b. Powder

c. Support bars

d. Filter aid

4.6.2 Theory — Fig.: Gauss vs. Pipe Diameter

a. Magnet strength

b. Comparison with conventional septum

4.6.3 Applications

a. UNOP tests, 3" diameter

4.6.4 Operational problems

a. Establishment of bed

b. Recovery of powder

c. Corrosion of powder

4.6.5 Design considerations

a. Pressure drop

b. Rupture strength

c. Weight limitations

d. Shaping of pole pieces

4.7 Edge Filter (Cuno)

4.7.1 Description — Fig.: Edge Filter

4.7.2 Applications

5.0 Filtration (Gas-Liquid and Gas-Solid)

5.1 Introduction

5.1.1 Importance (biological)

5.1.2 Efficiency required

5.1.3 Mechanisms

5.2 AEC Paper

5.2.1 Scope

a. Particle size for which effective

b. Particle concentration for which suitable

c. Capacity

d. Other limitations

5.2.2 Applications

a. Calciner off gas - SR

b. Waste incinerator off gas - ANL

c. Etc. (widely used)

5.2.3 Filter replacement methods

5.3 Bag Filters

5.3.1 Scope

a. Particle size

b. Particle concentration

c. Capacity

d. Other limitations

5.3.2 Applications

a. Calciner off gas - SR, Hanford

5.3.3 Bag changing technique

5.4 Sand Filters

5.4.1 Scope

a. Particle size

b. Particle concentrations

c. Capacity

d. Pressure drop

5.4.2 Applications

a. Hot off gas - SR, Hanford

5.5 Fiberglas Filters

5.5.1 Scope

a. Particle size

b. Particle concentration

c. Capacity

5.5.2 Applications

a. Process off gas lines

b. Service lines

5.5.3 Design considerations

a. Fiber size

b. Packing density

5.6 Electrostatic Precipitators

5.6.1 Scope

a. Particle size

b. Efficiency

5.6.2 Applications

5.6.3 Design

a. Voltage required

b. Geometry

5.6.4 Operational difficulties

6.0 Fluidization (Gas-Solid)

6.1 Introduction

6.1.1 Characteristic features of radiochemical applications

6.2 Theoretical Background

6.2.1 Types of fluidized beds

6.2.2 Particle size and size range

6.2.3 Pressure drop

6.2.4 Entrainment

6.2.5 Heat transfer

6.3 Applications

6.3.1 $UF_4 \longrightarrow UF_6$ (England)

6.3.2 UNH $\longrightarrow UO_3$ (see Calcination)

6.3.3 ANN $\longrightarrow Al_2O_3$ (see Calcination)

6.3.4 UF_4 dehydration - UNOP

7.0 Physical Treatment

7.1 Introduction

7.2 Materials Handling

7.2.1 Slug charging — Fig.: Slug Charging Mechanism

a. Universal loader - UNOP

7.2.2 Solids discharging dissolver - UNOP

Fig.: Continuous Solids Discharging Dissolver

7.2.3 Fission product separation, special equipment for

7.3 Physical Separations

7.3.1 Sawing

7.3.2 Grinding

7.3.3 Dejacketing — Fig.: Operation of Dejacketing Devices

a. Banana peeler

b. Unwinder

c. Derodder — Fig.: McIntosh-Hemphill Derodder

7.3.4 Chopping

Outline for Chapter VI

FLUID FLOW

1.0 Introduction

2.0 Piping and Pipe Connections

3.0 Pumps

4.0 Valves

1.0 Introduction

2.0 Piping and Pipe Connections

2.1 Introduction

2.1.1 Importance of integrity

2.1.2 Need of connections for maintenance reasons

a. Relation to type of maintenance

2.1.3 Tubing vs. pipe

2.1.4 Thermal expansion

2.1.5 Head losses calculated by conventional means

2.2 Welded Joints

2.2.1 Specifications

2.2.2 Welder qualification

2.2.3 Inspection

2.2.4 Screwed connections, back-welded

2.3 Flanged Joints

2.3.1 Gasket types and materials

Fig: Gaskets suitable for radiochemical use

2.3.2 Gasket measurement - HRT-CP

Fig: Device for accurate gasket measurement

2.3.3 Bolt expansion - HRT-CP

a. Belleville springs

. <u>Fig:</u> Belleville springs

b. Ferrules and counterbore

c. Other

2.3.4 Leak detection - HRT-CP

2.4 Tubing Fittings

2.4.1 Types

a. Flared

b. Compression

2.4.2 Tendency to weep

2.5 Quick Disconnects

2.5.1 Types

a. RaLa design

b. Graylok

c. Nicholson-Irvine design

<u>Fig:</u> Quick disconnects for underwater maintenance

d. Other

2.5.2 Applications

a. Decontamination lines - Thorex

b. Service lines - ICPP (jets, spargers, jackets not normally used)

c. Instrument lines - MCFPPP

2.6 High Pressure Fittings

2.6.1 Description

2.6.2 Applications

a. HRT-CP

b. Centrifuge plow hydraulic controls

c. Centrifuge sluicing sprays

2.7 Remote Disconnects - See Chapter II

3.0 Pumps

3.1 Introduction

3.1.1 Characteristics

a. Capacity

b. Head

c. Power

d. Efficiency

e. Reliability

3.1.2 Special seals

<u>Fig</u>: Seals for pumps in radiochemical applications

a. Leakage specifications

3.2 Turbine Pumps

3.2.1 Distinguishing characteristics in radiochemical applications

3.2.2 Types

a. Deep well - Hanford

<u>Fig</u>: Deep well turbine pump

b. Regenerative - Redox

<u>Fig</u>: Regenerative turbine pump

3.2.3 Operational difficulties

3.2.4 Design

3.3 Piston Pumps

3.3.1 Distinguishing characteristics

3.3.2 Applications

a. Metering cold streams

b. ----- KAPL

3.3.3 Operational difficulties

3.3.4 Design

3.4 Gear Pumps

3.4.1 Distinguishing characteristics

3.4.2 Applications

3.5 Centrifugal Pumps

3.5.1 Characteristics distinguishing them in radiochemical applications

3.5.2 Applications

3.6 Canned Rotor Pumps

3.6.1 Distinguishing characteristics

Fig: Canned rotor pump developed for radiochemical use

3.6.2 Applications

a. HRT-CP

b. BrF_3 - BNL

c. Solvent recovery - ICPP, Hanford, Thorex

d. Metal recovery (ORNL)

3.6.3 Operational difficulties

a. Alignment

b. Bearing lubrication

3.6.4 Design considerations

3.7 Hytor

3.7.1 Distinguishing characteristics

3.7.2 Applications

a. Offgas vacuum

b. Filter vacuum

3.7.3 Design considerations

3.8 Diaphragm Pumps

3.8.1 Characteristics of applications which distinguish them from conventional

. . Fig: Remote head diaphragm pump

3.8.2 Applications

a. Solvent extraction feed - ICPP, ORNL

b. HRT solids injection

3.8.3 Operational problems

3.8.4 Design considerations

3.9 Progressing Cavity Pumps (Moyno)

3.9.1 Distinguishing characteristics

3.9.2 Applications

a. Waste sampling - ICPP

b. Slurries

c. Highly concentrated UNH solutions

3.9.3 Operational problems

3.9.4 Design considerations

3.10 Peristaltic Pumps

3.10.1 Distinguishing characteristics

Fig: Two types of Peristaltic pump

3.10.2 Applications

a. Development work

b. Early times

3.10.3 Operational difficulties

3.10.4 Design considerations

3.11 Steam Jets

3.11.1 Characteristics which distinguish them for radiochemical applications

3.11.2 Applications

a. Hot feed - SR

b. Waste evaporator feed - ICPP, SR

c. Sampling - $BiPO_4$, "25" pilot plant (ORNL), Redox pilot plant (ORNL)

d. Internal recirculation of decontaminating solutions - ICPP, Thorex

e. Metering solvent - ORNL Metal Recovery

f. Metering feed - ORNL Metal Recovery

g. Elevating feeds - ORNL Metal Recovery

h. Offgas vacuum - ORNL Pilot Plant

3.11.3 Operational difficulties

a. Dilution

b. Temperature increase

c. Vapor lock

3.11.4 Design considerations

3.12 Air Jets

3.12.1 Distinguishing characteristics

3.12.2 Applications

a. Sampling

3.12.3 Design considerations

3.13 Displacement Pumping

3.13.1 Distinguishing characteristics

3.13.2 Types

a. Displacement gas (blow case)

(1) Final product transfer, ICPP

(2) Molten salt transfer - Volatility Pilot Plant

b. Displacement liquid: methylcyclohexane - hot feed, "25" pilot plant

c. Displacement solid - lowering tank into tank (France)

3.13.3 Operational problems

a. Control difficulty (gas)

3.13.4 Design considerations

3.15 Airlifts

3.15.1 Distinguishing characteristics

a. No moving parts

3.15.2 Applications

a. Hot feed metering - ICPP (expanded), Thorex

3.15.3 Operational difficulties

a. Entrainment in off-gas

b. Plugging in concentrated solutions

3.15.4 Design considerations

3.16 Vapor Transfer (Temperature Differential)

3.16.1 Description

3.16.2 Applications

a. UF_6 transfer - ORNL-VPP, ANL

3.16.3 Design considerations

3.17 Egyptian Water Wheel

3.17.1 Description

3.17.2 Applications

a. EBR blanket processing plant feed

4.0 Valves

4.1 Introduction

4.1.1 Characteristics of applications which distinguish them from conventional applications

4.1.2 Types of applications

a. Flow control

b. Flow interruption

c. Check valves

(1) Pulse column use

(2) Other uses

d. Safety valves and frangible disks

e. Instrument valves

4.2 Mechanical Valves

4.2.1 Special features for radiochemical use

a. Operator

(1) Bellows

(2) Diaphragm

(3) Extension handles

(4) Motor

(5) Solenoid - Redox pilot plant sampling valve

b. Seal

(1) Bellows

(2) Packed

(3) Diaphragm

c. Seat

(1) Teflon - developed at ORNL

(2) Stellite stem, S. S. seat - ICPP

(3) Stellite seat, S. S. plug - HRT

(4) Hastelloy seat, Carpenter 20 plug - HRT

(5) Etc.

4.3 Freeze Valves

4.3.1 Characteristics which distinguish them for radiochemical use

4.3.2 Applications

a. HRT-CP

Fig: Freeze valve in aqueous line

b. Molten salt - Volatility Pilot Plant

Fig: Freeze valve in molten salt line

c. Thorex

4.3.3 Operational difficulties

4.3.4 Design considerations

4.4 Air Block Valve (Irvine)

4.4.1 Description

Fig: Irvine air block valve

4.4.2 Application

a. Recycle process system - Thorex

Outline for Chapter VII

HEAT TRANSFER OPERATIONS

1.0 Introduction

- 1.1 Mechanisms
- 1.2 Governing Philosophy
  - 1.2.1 Avoid contamination of cooling or heating medium
    - a. Recirculation of medium
  - 1.2.2 Avoid introduction of medium into process stream
  - 1.2.3 Ease of equipment decontamination

2.0 Heat Transfer Without Change of Phase

- 2.1 Introduction
- 2.2 Jacketed Vessels
  - 2.2.1 Advantages in Radiochemical Plant
  - 2.2.2 Applications
    - a. Dissolvers - $BiPO_4$, ICPP, ORNL pilot plant, HRT-CP
    - b. $BiPO_4$ metal solution storage tanks
    - c. Feed make-up tanks
    - d. Decay storage tanks - HRT-CP
  - 2.2.3 Operational problems

2.2.4 Design

a. Heat transfer coefficients

2.3 Coils Inside Vessels

2.3.1 Advantages

2.3.2 Applications

a. $BiPO_4$ dissolvers, etc.

b. Sr, extensively

c. Dissolver - RaLa

2.3.3 Operational difficulties

a. Leaks

b. Decontamination

2.3.4 Design

a. Heat transfer coefficients

2.4 Coils Wrapped Around Vessels

2.4.1 Advantages in radiochemical plant

2.4.2 Applications

a. ANL volatility

2.4.3 Design calculations

a. Area determination

b. Heat transfer coefficients

2.5 Shell-and-Tube Heat Exchangers

2.5.1 Applications

a. Liquid nitrogen cooling of offgas charcoal beds

2.5.2 Operational prbblems

2.5.3 Design

2.6 Steam Spargers

2.6.1 Advantages in radiochemical plant

2.6.2 Applications and disadvantages

a. $BiPO_4$ dissolver

b. ICPP (optional)

c. Other

2.6.3 Operating problems

2.6.4 Design considerations

2.7 Electric Resistance Elements

2.7.1 Advantages and disadvantages in radiochemical plant

a. High heat flux obtainable

b. Ease of control

c. Tendency to burn out

2.7.2 Applications

a. Furnaces - ORNL-VPP

b. Strip heaters - ORNL-VPP, HRT-CP

c. Finned strip heaters in offgas - $BiPO_4$, Redox

d. Resistance cable - UF_6 transfer lines

e. Immersion heaters

2.7.3 Design considerations

a. Maximum permissible surface temperature

b. Spacing to provide uniform heat distribution

2.7.4 Special techniques

a. Casting Inconel-tubing heaters in high copper alloy or aluminum

2.8 Electric Autoresistance Heating

2.8.1 Description and advantages

Fig: Autoresistance heating installation

2.8.2 Applications

a. ORNL-VPP

2.8.3 Operational problems

a. Impedance balancing

b. Stray currents

c. Input terminal

Fig: Temperature control at input terminal

2.8.4 Design considerations

a. Current requirements

Fig: Temperature distribution at pipe junctions

b. Heat losses at fittings or terminals

c. Insulation uniformity

2.9 Induction Heating

2.9.1 Description and advantages

2.9.2 Applications

a. Oxide slagging

b. Zone melting

2.9.3 Operational problems

a. Size of power supply

2.9.4 Design considerations

2.10 Pump Energy

2.10.1 Use for HRT loops

3.0 Boiling and Evaporation

3.1 Introduction

3.1.1 Theoretical background

3.1.2 Vapor recompression - BNL waste

3.1.3 Control considerations

3.2 Steam-Jacketed Pot

3.2.1 Application

a. Intercycle evaporator - "25" process

3.2.2 Operational problems

3.2.3 Design

a. Heat transfer coefficients

3.3 Conventional Shell-and-Tube Boiler

3.3.1 Applications

a. Hanford waste

3.3.2 Operational difficulties

3.3.3 Special techniques

a. Joining tubes to tube sheets

3.3.4 Design

3.4 Vertical Tube, Gravity Recirculation

3.4.1 Advantages for radiochemical use

3.4.2 Applications

a. Purex - Hanford

b. "25" process - ICPP

3.4.3 Operational problems

3.4.4 Design

3.5 Bayonet Tube Bundles

3.5.1 Advantages in radiochemical plant

3.5.2 Applications

a. Hexone recovery still - ICPP

b. Purex, Redox - Hanford

3.5.3 Operational problems

a. Condensate reheating

Fig: Bayonet tube bundle for remote maintenance plant

3.5.4 Design

3.6 Internal Coils in Pot

3.6.1 Advantages in radiochemical plant

3.6.2 Applications

a. Redox ICU

b. SR

3.6.3 Operational problems

a. SR burnout

3.6.4 Design calculations

3.7 Falling Film Evaporator

3.7.1 Applications

a. "25" pilot plant - intercycle evaporator

3.7.2 Operational problems

a. Control

3.7.3 Design

3.8 Glycerine Bath

3.8.1 Applications

a. $BiPO_4$ product concentration

3.8.2 Difficulties

3.9 Flash Evaporation Development - SR

4.0 Vapor Condensation

4.1 Introduction

4.1.1 Theoretical background

4.1.2 Updraft vs. downdraft

4.1.3 Effect of large quantities of inerts

4.1.4 Snow or fog formation

Fig: Conditions for fog formation in condensers

4.2 Conventional Shell and Tube

4.2.1 Applications - ICPP, Hanford, ORNL

4.2.2 Operational problems ?

4.2.3 Design - conventional

4.3 Shell and Finned Tube, Vapor Outside Tube, Falling Film

4.3.1 Description

4.3.2 Applications

a. Redox

b. Purex - Hanford

4.3.3 Design considerations

4.4 Jacketed Pipe

4.4.1 Applications

a. Coolers - expanded ICPP, Thorex

4.4.2 Design - conventional

4.5 Coil Within Vessel, Vapor Outside Coil

4.5.1 Advantages in radiochemical plant

4.5.2 Applications

a. Sr, almost universally

b. Dissolver offgas - $BiPO_4$

4.5.3 Operational problems

4.5.4 Design

a. Area determination

b. Outside film coefficient

c. Overall coefficient

d. Coil radius; spacing

4.6 Coil Within Vessel, Vapor Inside Coil

4.6.1 Applications

a. Offgas cold traps (liquid nitrogen coolant)

4.6.2 Design

a. Capacity

b. Fabrication techniques

4.7 Coils Wrapped Around Vessel; Spray Metal Bonded

4.7.1 Description and advantages in radiochemical plant

<u>Fig</u>: Bonding of cooling coils to condenser shell

4.7.2 Applications

a. ANL volatility

4.7.3 Design

a. Coil area requirement

b. Calculation of mean path through metal

<u>Fig</u>: Determination of mean heat path

c. Overall coefficients

(1) Water in coil

(2) Air in coil

4.8 Contact Condenser

4.8.1 Advantages and limitations in radiochemical plant

4.8.2 Applications

a. Hanford low level activity

4.8.3 Design - conventional

4.9 Egg-Crate Baffled Cold Traps

. . 4.9.1 Description and advantages

Fig: Extended surface for UF_6 cold trap

4.9.2 Applications

a. ORNL-VPP

4.9.3 Design

a. Capacity

b. Baffle spacing Fig: Calculation of baffle spacing

c. Thermal stresses

4.10 Fluidized Cold Trap

4.10.1 Description

Fig: Continuous cold trap

4.10.2 Advantages

a. Continuous

4.10.3 Possible applications

a. UF_6 - volatility

b. $ZrCl_4$ - Zircex

4.10.4 Design

a. Capacity

b. Heat transfer coefficients

c. Stripping section

d. Entrainment collection

5.0 Calcination

5.1 Introduction

5.2 Stirred Pot Calciner

5.2.1 Description

a. Nature of product

5.2.2 Applications

a. UNH ---> UO_3

5.2.3 Operational problems

5.2.4 Design

a. Power requirement

b. Heat transfer

5.3 Screw Calciner

5.3.1 Description

Fig: Continuous screw calciner

a. Nature of product

5.3.2 Applications

a. UNH ---> UO_3

5.3.3 Operational problems

5.3.4 Design

a. Power requirements

b. Heat transfer

5.4 Fluidized Bed Calciner

5.4.1 Description

a. Nature of product

5.4.2 Applications

a. UNH ---> UO_3

b. Aluminum nitrate ---> Al_2O_3

5.4.3 Design

a. Fluidizing velocity

b. Heat transfer

5.5 Moving Bed

5.5.1 Description

5.5.2 Applications

a. UNH ---> UO_3

5.6 Furnace

5.6.1 Description

5.6.2 Applications

a. Thorium oxalate ---> ThO_2 - ORNL

5.6.3 Design

a. Heat requirements

b. Temperature and time of firing

5.7 Flame calciner ?

Outline for Chapter VIII

SOLVENT EXTRACTION

1.0 Introduction

- 1.1 Theory
  - 1.1.1 Distribution
  - 1.1.2 Equilibrium data
  - 1.1.3 Column functions
    - a. Extraction
    - b. Scrubbing
    - c. Stripping
  - 1.1.4 Calculation methods
- 1.2 Equipment Characteristics
  - 1.2.1 Throughput
  - 1.2.2 Flooding
  - 1.2.3 Stage efficiency

2.0 Mixer-Settlers

- 2.1 Introduction
- 2.2 Agitation

2.2.1 Mechanical stirring — *Fig.:* Mechanically Stirred Mixer-Settler

a. KAPL

b. SR

2.2.2 Pump-mix

a. KAPL — *Fig.:* KAPL Pump-Mix Mixer-Settler

b. SR — *Fig.:* Savannah River Pump-Mix Mixer-Settler

C. Whatley — *Fig.:* Whatley Mixer-Settler

2.2.3 Airlift

a. Chalk River — *Fig.:* Airlift Mixer-Settler

b. Harwell

2.2.4 Pulsed

a. Hanford

2.2.5 Ultrasonic

2.2.6 Shrouded paddle

a. SR

2.3 Design Considerations

2.3.1 Interfacial area

a. ANL (Rodger)

Fig.: Interfacial Area of Dispersed Phase

2.3.2 Stage efficiency

2.3.3 Density differences

2.3.4 Emulsion tendencies

2.3.5 Interface control

3.0 Pulse Columns

3.1 Introduction

3.1.1 Advantages — <u>Fig.</u>: Pulse Column

3.2 Applications

3.2.1 Purex - Hanford

3.2.2 Metal Recovery - Hanford, ORNL

3.2.3 "25" Process - ICPP

3.2.4 Thorex - ORNL

3.2.5 Other

a. Mallinkrodt

b. Fernald

3.3 Characteristic Features

3.3.1 Interface control

a. Dip lines

b. Capacitance probes

c. Floats

3.3.2 Backmixing

3.3.3 Emulsions and third phase

3.3.4 Interface crud

3.3.5 Pulsers — <u>Fig.</u>: Pulsing Mechanisms

a. Piston

b. Bellows

c. Steam

3.3.6 Flooding

a. Frequency - amplitude product, effect on

b. Relative flow rates, effect on

c. Extraction height, effect on

3.3.7 Determination of flooding

a. McNamee method   Fig.: Analytical Determination of Flooding

3.3.8 Determination of stage height

3.3.9 Pulse effects

a. Frequency - amplitude product

b. Wave form

c. Amplitude

3.3.10 Plate geometry

a. Spacing

b. Thickness

c. Size of perforations

d. Spacing of perforations

e. Number of perforations

3.3.11 Concatenation   Fig.: Diagram of Concatenated Pulse Column

a. Aqueous and organic check valves

3.3.12 Special plate design   Fig.: Special Pulse Column Plates

a. Zebra plates

b. Nozzle plates

c. Louver plates

4.0 Other Extraction Equipment

4.1 Packed Columns - Redox, ICPP

4.2 Spray Columns - LMFR Extraction

4.3 Rushton   Fig: Rushton Solvent Extraction Contactor

Outline for Chapter IX

OTHER MASS DIFFUSION OPERATIONS

1.0 Introduction

2.0 Gas-Liquid Absorption

3.0 Adsorption

4.0 Drying

5.0 Ion Exchange

6.0 Distillation and Rectification

7.0 Steam Stripping

1.0 Introduction

1.1 Equilibrium

1.2 Ideal Stages

1.2.1 Material balance

1.2.2 Operating lines

1.3 Calculation of Number of Ideal Stages

1.4 Calculation of Number of Transfer Units

1.5 The Rate Equation

1.5.1 Film theory

1.5.2 Fugacity differences

1.5.3 Diffusion

2.0 Gas-Liquid Absorption

2.1 Introduction

2.1.1 Theoretical background

a. Henry's law

b. Absorption coefficients

c. Transfer units

2.1.2 Gas holders

2.1.3 O_2 addition techniques

2.2 Wetted Wall Towers (down draft condensers)

2.2.1 Description

2.2.2 Use for removal of nitrogen oxides from dissolver offgas

2.2.3 Design

a. Gas rate; liquid rate; L/V

b. HTU

c. Pressure drop negligible

2.3 Packed Towers (Raschig ring packing)

2.3.1 Theory

2.3.2 Applications

a. Offgas de-entrainment - $BiPO_4$ dissolvers

b. Fluorine disposal - K-25, Paducah

2.3.3 Design

a. Capacity

b. Gas and liquid rates; L/V

c. Pressure drop

d. Flow distributors

2.4 Bubble Cap Columns

2.4.1 Theory

2.4.2 Use for HNO_3 recovery - SR, Hanford Purex

2.4.3 Operational problems ?

2.4.4 Design

a. H. E. T. S.

b. Liquid and gas rates; L/V

c. Pressure drop

2.5 Sieve Plate Column

2.5.1 Theory

2.5.2 Application to hot vessel offgas - Thorex

2.5.3 Operational difficulties ?

2.5.4 Design

a. H. E. T. S.

b. Liquid and gas rates; L/V

c. Pressure drop

2.6 Spray Towers

2.6.1 Theory

2.6.2 Applications

a. Fluorine disposal - ORNL-VPP

b. Interhalogen disposal - ANL-VPP

c. Dissolver offgas - ICPP

2.6.3 Operational difficulties

a. Entrainment

b. Corrosion

2.6.4 Design

a. Capacity

b. Gas and liquid rates; L/V

c. Pressure drop

d. Spray pattern

3.0 Adsorption

3.1 Adsorption

3.1.1 Theoretical background

a. Equilibrium data

b. Heat of adsorption

3.1.2 Effect of regeneration

3.1.3 Effect of fission product heat generation

3.2 Charcoal Beds

3.2.1 Equilibrium capacity

3.2.2 Applications

a. Kr and Xe removal

b. I_2 removal

3.2.3 Desorption

a. Time required

3.3 Silica Gel Beds

3.3.1 Equilibrium capacity

3.3.2 Applications

a. Zr-Nb from process wastes - KAPL

b. U-233 decontamination from Pa, Zr, Nb - Thorex

3.3.3 Desorption

3.4 Alumina

3.4.1 Capacity

3.4.2 Applications

a. Offgas drying before low-temperature beds - ICPP

b. Water removal from freon refrigerant - HRT-CP

c. Instrument air drying (commercial units)

3.5 NaF Beds

3.5.1 Capacity

a. HF

b. UF_6

Fig: UF_6 equilibrium with NaF at various temperatures

c. Fission product fluorides

3.5.2 Applications

a. HF removal from F_2 - VPP

b. Fission product removal from process stream - VPP

c. UF_6 safety traps

Fig: Concentration profile in UF_6 safety trap

3.5.3 Operational difficulties

a. Fines entrainment

b. UF_5 formation

c. Heat transfer difficulties

3.5.4 Desorption

a. UF_6 losses

b. Ability to re-use

3.6 $AgNO_3$ Coated Packing for I_2 Removal

3.6.1 Description

3.6.2 Capacity

3.6.3 Regeneration

4.0 Drying

4.1 Introduction

4.1.1 Theoretical background

4.2 UF_4

4.2.1 Crystal structure - 2.5 hydrate vs. 0.75 hydrate

Fig: Photomicrograph of UF_4 hydrates

4.2.2 Tray drying

4.2.3 Fluidized bed

4.3 RaLa Product

4.3.1 Infra-red plus aspiration

4.4 Gas Streams

4.4.1 Cold traps (see "condensation")

4.4.2 Desiccants (see "adsorption")

5.0 Ion Exchange

5.1 Introduction

5.1.1 Theoretical background

5.1.2 Cation resins

5.1.3 Anion resins

5.1.4 Radiation damage to resins

<u>Table</u>: Damage to selected resins exposed to radiation

5.1.5 Resin attrition

<u>Fig</u>: Attrition of Dowex-50 after 1000 hours circulation

5.1.6 Semipermeable membranes

5.2 Fixed Bed Exchangers

5.2.1 Upflow vs. downflow

5.2.2 Applications

a. Pu isolation - SR, Purex Pilot Plant, ORNL Metal Recovery

b. RaLa

c. U-233 recovery - Thorex

d. waste disposal

e. Canal water cleanup

f. Fractionation of radioisotopes

5.2.3 Design

a. Capacity

b. Regeneration

5.3 Higgins Contactor

Fig: Diagram of Higgins contactor

5.3.1 Description

a. Pulsing mechanism

Fig: Resin pulsing schemes

b. Slip-water ratio

c. Resin valves

5.3.2 Applications

a. Pu concentration - Hanford

b. Decladding stainless steel with H_2SO_4

c. Excer ?

d. Scrap recovery ?

e. 36-in. column

5.3.3 Design considerations

a. Capacity - loading and stripping sections

b. Pulse volume

5.4 Continuous Ion Exchange Equipment

5.4.1 Hydraulic ram

6.0 Distillation and Rectification

6.1 Introduction

6.1.1 Theoretical background

a. Vapor-liquid equilibrium

b. Theoretical stages and transfer units

c. Rectification and reflux

6.2 Batch Retorts

6.2.1 High-temperature metal separation

Fig: Equipment for distillation of Magnesium metal

6.2.2 Solvent recovery - Redox Pilot Plant, "25" Pilot Plant

6.3 Packed Columns

6.3.1 Advantages

6.3.2 Applications

a. Raschig rings for UF_6 - ORGDP

b. Cannon packing for UF_6 - ORGDP, ANL Volatility

c. Other - BNL Volatility (helices)

6.3.3 Design Considerations

a. Boil-up rate

b. Flooding

c. Holdup

d. Throughput

e. Reflux splitters

6.4 Bubble Cap Columns

6.4.1 Advantages

6.4.2 Applications

a. Darex all-glass column

6.4.3 Design

a. Conventional

6.5 Steam Distillation

6.5.1 Theory

6.5.2 Applications

a. Hexone recovery - Hanford

b. TBP removal - see "steam stripping"

6.5.3 Design

a. Conventional

7.0 Steam Stripping

7.1 Introduction

7.1.1 Theoretical background

7.2 Equipment

7.2.1 Packed columns

7.2.2 Bubble-cap columns

a. "25" process

b. Hanford Purex (intercycle)

7.2.3 Sieve plate columns

a. "25" process

7.2.4 ?

a. Hanford Redox ICU

b. Hanford Redox 3B effluent

c. Hanford Redox condensate stripper

Outline for Chapter X

INSTRUMENTATION

1.0 Introduction

- 1.1 Physical Measurements
- 1.2 Chemical Measurements
- 1.3 Remote Operation
- 1.4 Problems Introduced by Radiation
  - 1.4.1 Materials of construction
  - 1.4.2 Unit shielding
- 1.5 Typical Process Instrumentation Circuit

  Fig: Typical Process Instrumentation Chart

2.0 General Design Considerations

- 2.1 No Direct or Potentially Direct Connections Between Process and Operating Areas

2.2 Inaccessibleness of In-Cell Instruments During Operation

2.3 Duplication of Certain Components

2.4 Leak-Tight Systems

2.5 In-Cell and Out-Of-Cell Applications

2.6 Precision and Accuracy

2.7 Pneumatic and Electric Applications

2.8 Nature of Process Stream

2.9 Disposition of Signal

2.10 Type of Maintenance (Direct, Remote, Underwater)

3.0 Chemical Analysis by Means of Physical Properties

3.1 Boiling Point

3.2 Thermal Conductivity

3.3 Mass Spectrograph

3.4 pH

3.5 Light Absorption

3.6 Electrical Conductivity

4.0 Temperature

4.1 Thermocouples

4.2 Gas Bulbs

4.3 Resistance Thermometers

5.0 Pressure

5.1 Bourdon Tube

5.2 Manometer

5.3 Strain Gage

6.0 Flow

6.1 Orifices

6.2 Rotometers

6.3 Vane Anemometer

6.4 Change in Sight Glass Level

6.5 Metering Pumps with "Flow Checkers"

6.6 Magnetic Flow Meter

6.7 Thermal Flow Meter

6.8 Air Lift Pump Meter

7.0 Radiation

7.1 Process Stream Measurements

7.2 In-Cell Atmosphere Measurements

7.3 Operating Area Measurements

8.0 Mass

8.1 Scales

8.2 Strain Gages

8.3 Null Balance

9.0 Level

9.1 Gamma Transmission

9.2 Dip Leg

9.3 Thermal Level Probe

<u>Fig</u>: Thermal Level Probe

9.4 Sonic

10.0 Noise

10.1 Microphone

11.0 Specific Gravity

11.1 Dip Leg

12.0 Control and Read-Out Instruments

Outline for Chapter XI

AUXILIARY EQUIPMENT

1.0 Introduction

2.0 Carriers

3.0 Viewing Devices

4.0 Manipulators

5.0 Samplers

1.0 Introduction

2.0 Carriers

2.1 Introduction

2.1.1 I. C. C. regulations on radiation

2.1.2 Weight limitations

2.1.3 Truck vs. rail

2.1.4 Relation to plant maintenance philosophy

2.2 Solid vs. Aqueous Fuels

2.2.1 Hydrogen evolution from aqueous

2.3 Thermal Cooling

2.3.1 Evaporation from aqueous

2.4 Capacity and Shielding

Fig.: Carrier for Radioactive Materials

2.4.1 Criticality

2.5 Mechanical Details

2.5.1 Closure

2.5.2 Stainless steel lining for ease of decontamination

2.5.3 George Parker's unitized construction

3.0 Viewing Devices

3.1 Introduction

3.1.1 Difficulties and limitations

a. Cell wall thickness

b. Contamination

c. You can't see through stainless steel anyway

d. Darkening of glass and other radiation damage

e. Expense

3.1.2 Use for laboratories and small-scale facilities

3.2 Methods Used

3.2.1 Lead glass windows

a. Sampling stations - ICPP, Thorex

b. RaLa centrifuge observation - ICPP

3.2.2 $ZnBr_2$ solution windows

a. Radioisotope separation

3.2.3 Periscopes

a. Interface observation - ORNL Pilot Plant

3.2.4 Industrial TV

a. ORNL-VPP, HRT-CP

4.0 Manipulators

4.1 Introduction

4.1.1 Seldom used in chemical plants

4.1.2 Use in hot analytical

4.1.3 Use in radioisotope separation

4.1.4 Use in development work

4.1.5 Potential use in mechanical handling

4.2 Types of Manipulators

4.2.1 Master-Slave — <u>Fig.</u>: Master-Slave Manipulator

4.2.2 Mechanical-Rectilinear — <u>Fig.</u>: Mechanical Hands

4.2.3 Extraman — <u>Fig.</u>: Extraman

5.0 Samplers

5.1 Introduction

5.1.1 Representative sample

5.1.2 Avoid cross-contamination

5.1.3 Evaporation from own decay heat

5.1.4 Hazards

5.2 Samplers for Aqueous Solutions

5.2.1 Recirculating airlift

a. Original design

b. Hypo needle-diaphragm refinement

c. Landry float

<u>Fig.</u>: Recirculating Sampler for Aqueous Radioactive Solutions

5.2.2 Dip sampler - RaLa, $BiPO_4$, Redox

5.2.3 Remote pipet

5.2.4 HRT

5.2.5 Sample valve

5.3 Samplers for gases

5.4 Samplers for Molten Salt — <u>Fig.</u>: Sampler for Radioactive Molten Salt

Outline for Chapter XII

PLANT DESIGN

1.0 Preliminary Considerations

2.0 Process Design

3.0 Project Design

4.0 Hazards Study

5.0 Plant Start-up

1.0 Preliminary Considerations

1.1 Schematic Flow Sheet

1.1.1 Sources of design information

1.1.2 Major process steps and operating conditions

1.1.3 Plant capacity

1.1.4 Estimated space requirements

Fig.: Schematic Process Flow Sheet

1.2 Schedule

Fig.: Typical Plant Design Schedule

1.2.1 Process design

1.2.2 Project design

1.2.3 Fabrication

1.2.4 Construction

1.2.5 Start-up

1.3 Physical and Chemical Properties of Process Materials

1.4 Maintenance Philosophy

1.4.1 Direct

1.4.2 Remote

1.4.3 Underwater

1.4.4 Unit shielding

1.5 Location of Plant

1.5.1 Radiological hazard to surroundings

1.5.2 Proximity to reactor

1.5.3 Accessibility to transportation

1.5.4 Accessibility of utilities

1.5.5 Accessibility of labor

1.6 Waste Disposal (solid, liquid and gaseous)

1.6.1 Geological

1.6.2 Seismological

1.6.3 Meteorological

1.6.4 Hydrological

2.0 Process Design

2.1 Process Flow Diagrams

2.2 Material Balance Flow Sheet

2.3 Energy Balance Flow Sheet

2.4 Preliminary Design of Main Components

2.4.1 Size

2.4.2 Number of nozzles and locations

2.4.3 Instrumentation required

2.4.4 Materials of construction

3.0 Project Design

3.1 Engineering Flow Diagrams

<u>Fig.</u>: Typical Engineering Flow Diagram

3.1.1 Equipment layout (elevation)

3.1.2 Process piping

3.1.3 Utilities

3.1.4 Electrical supply

3.1.5 Instrumentation

3.2 Detailed Engineering Design

3.2.1 Vessel design

a. Capacity and major dimensions

b. Criticality

c. Decontamination

d. Materials of construction

e. Wall thickness

f. Welding specifications

g. Inspection specifications

h. Detailed construction drawings

3.2.2 Equipment design

a. Detailed specifications on mechanical equipment

3.2.3 Equipment and vessel layout

a. Plan and elevation drawings

3.2.4 Instrumentation

3.2.5 Piping design (process, instrument, air, water, conduit)

a. Inside cell

b. Outside cell

c. Wall penetrations

(1) Heat dissipation

(2) Radiation shielding

d. Sizing

e. Materials of construction

f. Wall thickness

g. Layout of various systems

3.2.6 Architectural

a. Plot plan

(1) Buildings

(2) Transportation

(3) Electrical substation

(4) Fuel element storage

(5) Waste storage

b. Main building

(1) Foundation

(2) Structural steel

(3) Cell wall

(4) Cell liners

(5) Cell drains

(6) Utilities

c. Auxiliary structures

(1) Analytical laboratory

(2) Machine shop

(3) Steam Plant

(4) Electrical substation

(5) Medical

(6) Health physics

(7) Stores

(8) Decontamination Facilities

(9) Plant Protection

(10) Stack

(11) Tank farm

3.2.7 Utilities

a. Steam

b. Process gases

(1) Air for spargers, jets, etc.

(2) Instrument air

(3) Blanket gases (N_2, He, H_2, O_2, etc.)

c. Water

(1) Potable

(2) Distilled

(3) Process

d. Electricity

(1) Emergency power

e. Ventilation

(1) Off gas (cell)

(2) Off gas (vessel)

(3) Off gas (lab hoods)

(4) Vacuum

(5) Air conditioning for instruments

4.0 Hazards Study

4.1 Nuclear Incident

4.1.1 Possibility of inadvertent criticality

4.2 Non-Nuclear Incident

4.2.1 Line break

a. Spread of radioactivity

4.2.2 Vessel leak

a. Spread of radioactivity

5.0 Plant Start-up

5.1 Cleanliness

5.1.1 Importance

5.1.2 During construction

5.1.3 After construction

5.2 Leak Testing

5.3 Vessel and Instrument Calibration

5.4 Initial Component Operation

5.4.1 Heat transfer coefficients on jacketed tanks

5.4.2 Jets

5.4.3 Pumps

5.4.4 Column

5.4.5 Evaporation

5.4.6 Samplers

5.4.7 Others

5.5 Cold Runs

5.5.1 Process simulated except for radioactivity

5.6 Hot Runs

5.6.1 Tracer

5.6.2 1% activity

5.6.3 10% activity

5.6.4 100% activity

Outline for Chapter XIII

PLANT OPERATION

1.0 General Considerations

2.0 Management

3.0 Operations

4.0 Analytical Operations

5.0 S. S. Accountability

6.0 Health Physics

7.0 Plant Protection

8.0 Maintenance

9.0 Utilities

10.0 Stores

1.0 General Considerations

1.1 Value of Process Material

1.1.1 Seriousness of losses

1.2 Radioactivity of Process Materials

1.2.1 Remote operation

1.2.2 Effect on plant design

1.2.3 Toxicity

1.3 Criticality

1.3.1 Effect on operation

1.3.2 Batch and concentration control

1.4 Investment in Plant and Operational Costs

1.4.1 Capacity operation desirable

1.4.2 Costly chemical reagents

8.3.1 Direct

8.3.2 Remote

8.3.3 Underwater

9.0 Utilities

9.1 Emergency Sources

10.0 Stores

Outline for Chapter XIV

FUEL REPROCESSING ECONOMICS

1.0 General Considerations

2.0 The Nuclear Fuel Cycle

3.0 Chemical Reprocessing in the Nuclear Fuel Cycle

4.0 Economic Comparison of Various Fuel Reprocessing Methods

5.0 Factors Affecting Reprocessing Costs

1.0 General Considerations

1.1 Value of Uranium and Thorium

1.2 Supply of Uranium and Thorium

2.0 The Nuclear Fuel Cycle

2.1 Definition — Fig.: "Typical Heterogeneous Fuel Cycle"

2.2 Comparison with Conventional Fuel Cycle

2.3 Effect of Fuel Cycle on Power Costs

2.3.1 Nuclear

2.3.2 Conventional

3.0 Chemical Reprocessing in the Nuclear Fuel Cycle

3.1 Purpose

3.1.1 Recover fissionable material

3.1.2 Decontaminate fissionable material

3.2 Cost of Chemical Reprocessing Relative to Other Steps

4.0 Economic Comparison of Various Fuel Reprocessing Methods

4.1 Introduction

4.2 Cooling Costs

4.3 Head End Treatment Costs

4.3.1 U-Al in HNO_3

a. Acid recovery

4.3.2 U-Al in NaOH

4.3.4 Th-Al in HNO_3

4.3.5 U-Zr in aqueous $HF-HNO_3$

4.3.6 U-Zr by HF in fused salt

4.3.7 U-SS in dilute aqua regia

4.3.8 U-SS in H_2SO_4

4.3.9 ThO_2 in HNO_3

4.4 Precipitation Process Costs

4.4.1 $BiPO_4$

4.4.2 MCFPPP (Multicurie Fission Product Pilot Plant)

4.4.3 RaLa

4.5 Solvent Extraction Process Costs

4.5.1 Extraction

4.5.2 Partition

4.5.3 Second uranium cycle

4.5.4 Second plutonium cycle

4.5.5 Third uranium cycle

4.5.6 Intercycle evaporation

4.5.7 Plutonium isolation

4.5.8 Solvent recovery