Questions for state doctoral exam – field of study: Chemical and Process Engineering
Topic: Unit Operations of Chemical Engineering

1. Fluid flow through pipelines and fluid transport. Basic concepts - forces acting in fluids, tangential and normal stress, pressure. Newton's law of viscosity, ideal fluid, Reynolds number. Velocity profile in laminar and turbulent fluid flow through a tube. Description using balances - continuity equation, Bernoulli's equation. Dissipation of specific mechanical energy during fluid flow through a pipeline. Pump power and output, suction and discharge head of the pump. Piping and centrifugal pump characteristics, operating point. Mixing liquids with rotary stirrers. Types of stirrers, mixing vessels, buffers. Criteria important for the description of mixing, power characteristics of the stirrer, determination of the power input of the stirrer.

2. Filtration. Darcy's law for pressure drop in fluid flow through a layer of granular material. Definition of quantities: void fraction, specific surface, superficial and interstitial velocity. Principles of cake filtration, filter press, other types of filters. Mass balance of filtration. Kinetic equations of filtration, washing of the cake.

3. Settling. Balance of forces acting on the settling particle, terminal velocity. Dimensionless numbers that follow from this equation and other criteria useful in the calculations. Effects of the character of flow on the drag coefficient, dependence on the Reynolds number. Procedure for terminal velocity calculation and particle diameter calculation. Area of gravitational settler with vertical and horizontal flow. Principle and description of cyclone and wind classifier operation. Hindered settling - dependence of the settling rate on the volume fraction of particles in the suspension.

4. Fluidization. Balance of forces acting on the fluidized bed. Comparison of the magnitude of individual forces and the dependence of the pressure loss on the superficial velocity of the fluid flowing through the fluidized bed from values lower than the threshold fluidization velocity up to the escape-terminal velocity. Calculation of threshold velocity and escape velocity. Criteria useful in calculations. Description of fluidized bed expansion.

5. Heat exchangers. Basic concepts - heat sharing mechanisms, Fourier's law, Newton's law of cooling, temperature profile near the heat exchange surface. Fourier-Kirchhoff equation, heat exchange criteria, heat transfer coefficient and its calculation. Heat transfer through a planar or cylindrical wall: heat transfer coefficient, resistance to heat transfer and temperature distribution. Heat exchangers - types of heat exchangers, temperature distribution along the exchangers with different flow arrangements. Total enthalpy balance of the exchanger. Logarithmic mean temperature difference and calculation of the heat exchange area of the exchanger.

6. Evaporators, basic types of evaporators. Mass and enthalpy balance of a single-member evaporator, effective temperature difference and temperature losses. Temperature distribution in the evaporator. Reduction of consumed heating steam, arrangement of flows in a multi-element evaporator.

7. Liquid extraction. Types of extractors and their arrangement. i) System with immiscible solvents: Expression of phase equilibrium, idea of equilibrium degree, efficiency of nonequilibrium degree. Graphic and numerical solution of single-stage and repeated extraction. Countercurrent stage extraction. ii) Extraction in the case of partially miscible solvents: Expression of the equilibrium for the

three-component mixture in the triangle diagram. Balance relations for one equilibrium extraction stage, lever rule. Graphic determination of raffinate and extract composition. Repeated extraction procedure. Necessary balance relations for a stage extractor with countercurrent contact of limited miscible phases, sum and difference current, representation in a triangular diagram. Graphic procedure for determining the number of extraction stages.

8. Distillation and rectification. Description of liquid-vapor phase equilibrium. Vapor pressure, relative volatility. Material balances of flash and batch (differential) distillation. Graphic solution of flash distillation. Continuous stage rectification: Scheme and principle of operation of equipment for continuous rectification. Balance needed to determine the number of equilibrium stages in the distribution diagram, graphical solution. Limit cases of rectification column operation. Enthalpy balance of column and condenser, influence of feed state on column operation.

9. Dryers. Basic concepts in solids drying: properties of humid air, enthalpy diagram of humid air, material moisture, equilibrium isotherm, first and second drying periods. Batch dryer material balance, drying time. Material and enthalpy balance of continuous countercurrent dryer and calorifer. Construction of some dryers. Spray drying - principle of operation, material and enthalpy balance at the dryer level and at the particle level, development of the morphology of the dried particle.

10. Basics of description of mass exchangers. Types of mass transfer, processes and equipment in which mass transfer is applied. Relationships for the intensity of diffusion and convective molar flux of a component in a homogeneous mixture. Component continuity equations, special cases of this equation. Description of interfacial equilibrium. Mass transfer and permeation, concentration profile of the shared component during mass permeation. Equations for mass transfer. Determination of mass transfer coefficient, criteria used in calculations. Mass transfer equations, the relationship between the transfer coefficient and the mass transfer coefficients. Representation of the driving forces of transfer and mass transfer in the distribution diagram.

11. Absorption. Types of absorbers with step and continuous phase contact. Flooding of the column with liquid. Balance and equilibrium relations needed to calculate the countercurrent stage absorber. Graphical representation in the distribution diagram, minimum solvent flow and determination of the number of equilibrium stages. Murphree efficiency, a procedure for graphical determination of the number of real stages. Linear equilibrium - definition of absorption factor and effect, relationship between number of degrees, absorption factor and effect, use in design and control calculation. Balance and velocity relationships for the packed absorber and with the countercurrent continuous phase contact needed to determine the packing height. Height and number of transmission units. Relationship between number of transfer units, absorption factor and effect at linear equilibrium, use in design and control calculation.

12. Membrane processes. Types of membrane separations, driving forces, practical use. Types of membranes used. Membrane modules. Material balance of the membrane module with ideal mixing on the permeate and retentate side. General rate relationship for expressing the flow rate of a component through a membrane, permeability and selectivity of the membrane, rejection / retention factor, ideal membrane. Determination of membrane area. Concentration polarization. A more detailed description

of some membrane processes: relations for expressing the component flow intensity during micro / ultra / nano-filtration, description of concentration polarization and gel formation. Relationships and equations used in reverse osmosis, gas permeation and pervaporation.

13. Mechanics of bulk materials. Forces acting in a layer of bulk material at rest and during flow. Angle of internal friction, angle of friction against the wall, Janssen's equation, conditions of bulk mass flow. Apparatus for storage, transport, separation and classification of bulk materials.

14. Grinding. Grinding mechanisms and types of mills. Energy consumption during grinding. Grinding speed, daughter particle size distribution function. Population balance of batch and flow mill. Mill-classifier system with recycling.

15. Agglomeration. Mechanisms of particle agglomeration and apparatus for agglomeration. Agglomeration kinetics, population balance of batch and continuous agglomeration.

16. Crystallization. Phase equilibria in liquid-solid systems, supersaturation of solution, classification of crystallization processes and apparatuses according to the method of supersaturation. Kinetics of nucleation and crystal growth. Mass, enthalpy and population balance for batch and continuous crystallization.

17. Adsorption. Principle, examples of industrially important adsorbents and adsorption separation processes. Equilibrium adsorption isotherms, temperature dependence. Material and enthalpy balance of the differential section of the adsorption column, concentration wave motion, breakthrough curve. Methods of adsorption column regeneration, Skarstrom cycle.