CHAPTER NINE : THE FUNDAMENTALS OF DESIGN

9.1 The Design Problem

Science teaches about natural things and how they work. Engineering is about how artificial things are designed and constructed to serve some useful purpose. Engineering design is a blend of *synthesis* and *analysis*. "*Synthesis* deals with the creation of artificial things that have desired properties by combining often diverse elements into a coherent whole. *Analysis* examines the elements and their relations. Each synthesis creates an analysis problem, the solution of which often provides insights that create a new synthesis".

The basic elements that are organized into pollution prevention and control systems are:

- *Reactors* in which chemical and biochemical reactions are promoted and controlled so that toxic, offensive, unstable, or low value materials can be transformed into non-toxic, inoffensive, stable, and useful materials.
- *Separation processes* that will concentrate or upgrade a material by selectively removing one species of material from another (solids from a liquid, for example).

Process synthesis cannot be studied without learning about transformations and separations, which are the subjects of other books. Analysis can be understood and practiced without knowing about the machinery that is used to accomplish the transformations and separations. We only need to know what change is accomplished or required.

9.2 The Fundamental Concepts

There is little hope of an effective solution until the designer knows the amounts of material and energy that will be managed. In an existing system one might install meters, gauges, and instruments to measure flow rates and chemical composition. Information can be tallied from production records, waste shipping manifests, and product specifications. But this will not provide all the needed information for two reasons, one technical and one philosophical.

The technical reason is that some quantities are not immediately available and can be obtained only by deductive reasoning from fragmentary available data. Certain kinds of effluents cannot be detected without extreme expenditures of time and money, if at all. Sometimes we cannot afford the luxury of making measurements, especially if the same information can be generated by scientific inference.

The philosophical reason is that we are concerned not only with the way things are but with the way things ought to be. Many of the systems we analyze exist only as alternatives in our mind, or on paper. We cannot measure that which does not yet exist but, we must have accurate estimates of the flow rates and compositions in order to assess alternate designs. This is done by using the two fundamental concepts shown in Figure 9.1.

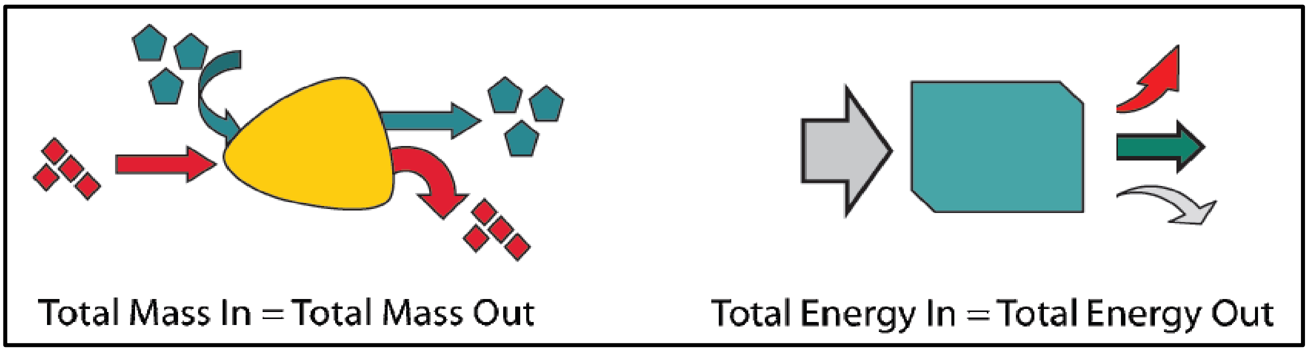

Figure 9.1: The fundamental principles: Conservation of Mass and Conservation of Energy

Conservation of Mass – Mass is neither created nor destroyed. All material flowing into and out of a system must be accounted for.

Conservation of Energy – Energy is neither created nor destroyed. All energy flowing into and out of a system must be accounted for.

The two most important design tools – the material balance and the energy balance – derive from these principles. Large chunks of material and molecules can be changed within the system. Water becomes steam, steam becomes water, fuel becomes gas, particles dissolve, solutes precipitate, gases are absorbed by or stripped from liquids, and so on. Molecules are decomposed and the atoms are rearranged to make molecules of new materials. Whatever happens within the system, the mass that enters either leaves or is stored within the system. The same is true for energy. Energy can be dissipated from a useful form into waste heat by friction or heat loss from steam pipes. Heat energy can become mechanical energy as when steam is used to drive a generator shaft. Mechanical energy can become kinetic energy as when a pump imparts motion to a fluid. After nature has done all the manipulations the total amount of energy must be the same. Some careful analysis may be needed to account for everything, but the Second Law of Thermodynamics says that the account must balance. The concepts are easy to understand and the calculations are readily learned. In practice the more difficult work estimating or collecting the necessary information about the flow and composition of the input and output streams.

9.3 The Material Balance and the Energy Balance

A material balance will be needed for virtually every pollution prevention and control problem. The material balance and the energy balance are needed when accounting for the use and flow of energy.

The material balance is used to answer such questions as:

- How will the amount of chemical sludge change if different chemicals are used to remove turbidity from river water?
- How much disinfectant per month must be purchased in order to achieve a specified disinfectant concentration in drinking water?
- How should the biological solids in a wastewater treatment plant be managed to yield a high quality effluent?
- How much useful (combustible) biogas will be produced in a landfill?
- How much sewage sludge must be blended with the solid refuse of a city to produce useful compost?
- How much sulfur dioxide will be emitted in the stack gas of a power plant per ton of coal burned?
- How much wastewater and sludge will be created by using lime slurry to scrub sulfur dioxide from stack gas?
- How much water is needed to rinse and clean parts in metal plating?
- Will waste chloride discharged from a proposed industry exceed what is tolerable in a river?

The energy balance is used to answer such questions as:

- How much heat energy can be obtained from biogas that is extracted from a landfill?
- How much heat energy can be recovered from the hot exhaust of a gas engine?
- Does a sludge digester produce enough biogas to heat the sludge that enters the digester?
- How much steam and cooling water can be saved by increasing the efficiency of a heat exchanger network?
- How much air must be supplied to an incinerator for efficient combustion of a waste gas?
- How much power is needed to supply air for activated sludge treatment of wastewater?

9.4 Block Diagrams

A variety of drawings are used from conception to final design of a project. To begin, when the process is mostly still in our imagination, block diagrams are used to show the process components and the flow of material and/or energy between them.

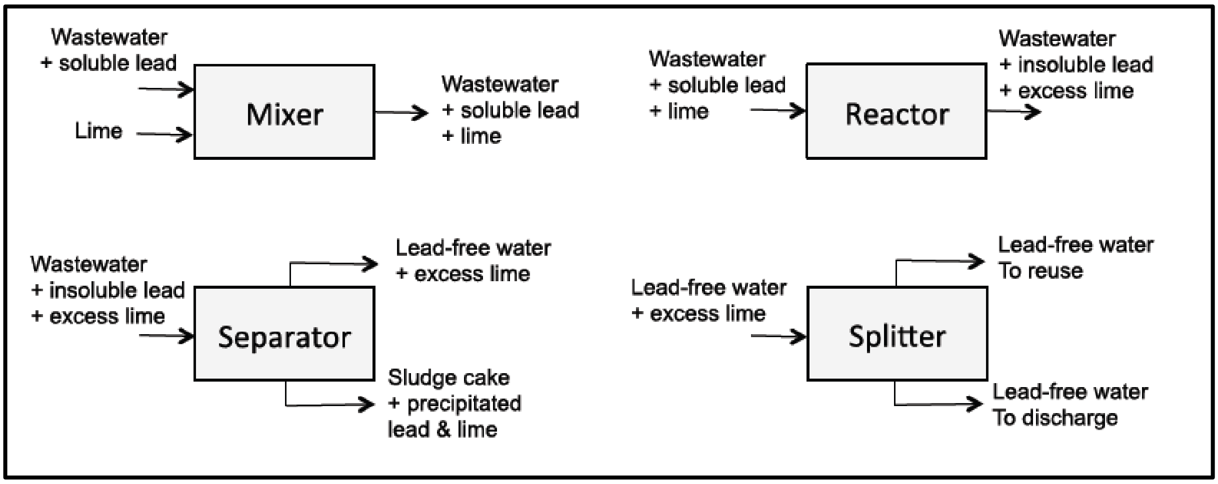

Figure 9.2: Diagrams of the four basic process components

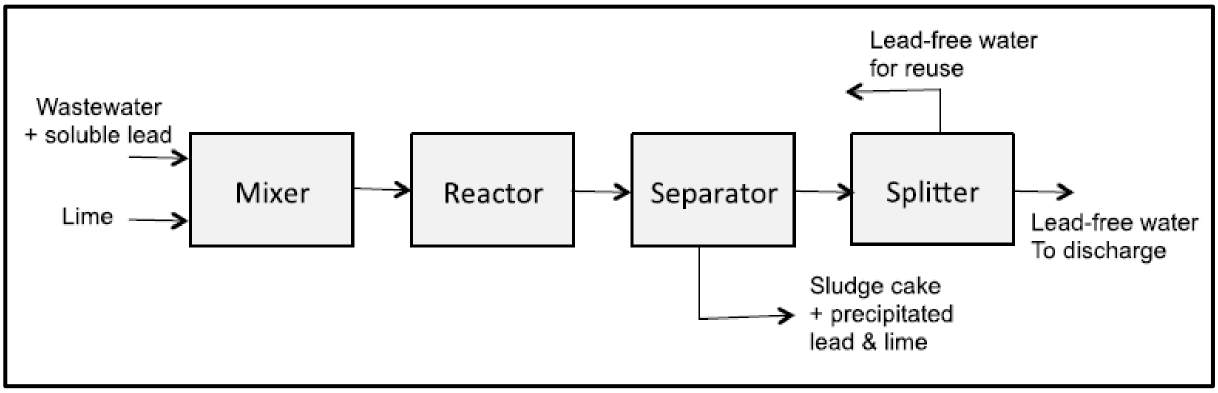

Figure 9.3: Process block diagram or flow sheet for a hypothetical lead removal process

9.5 Block Diagrams and the Material Balance

Figure 9.4 shows how the block diagram is used to organize the material balance. The block diagram shows a three-stage solid-liquid separation sequence and the mass of water and solids entering and leaving each stage. At each stage, the mass of water in equals the mass of water out. The same is true for the solids and for the total mass (water + solids). The influent solids concentration is 2% (2 T/100 T) and the solids leave the centrifuge at a 25% concentration (2 T/8 T). Three stages are used because each separation process is restricted on the solids concentration it can accept as feed and how much thickening it can do.

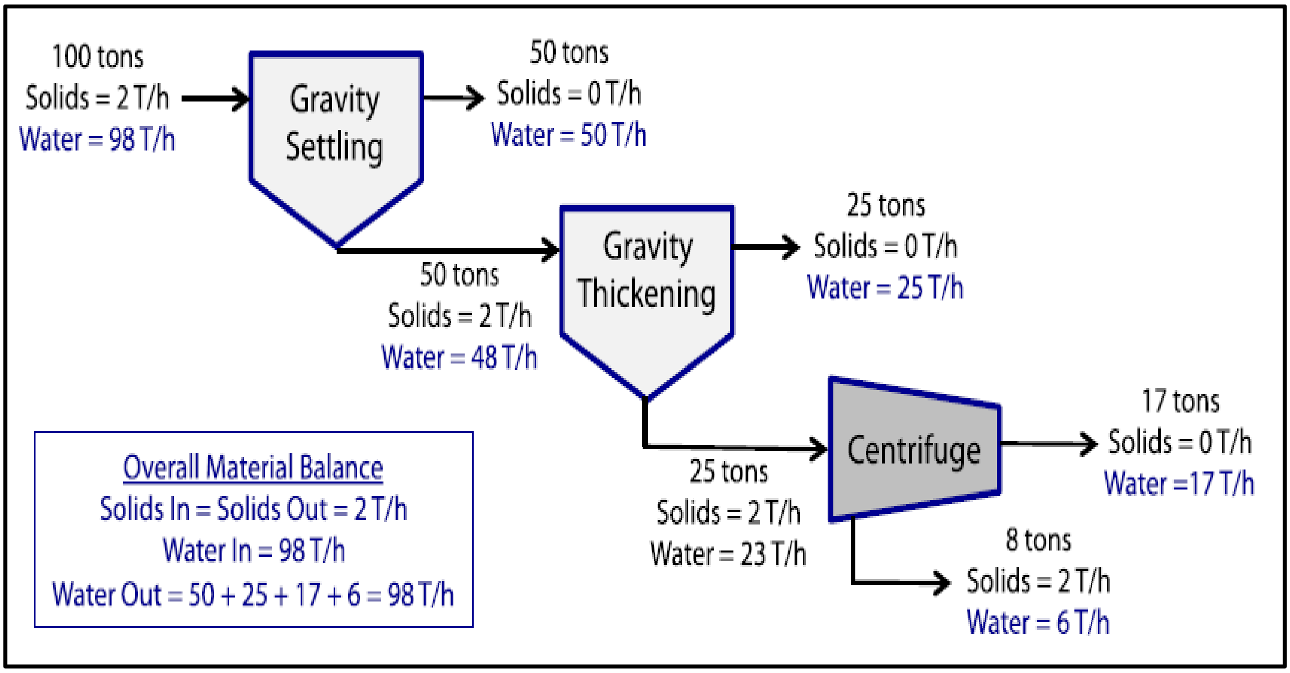

Figure 9.4: Block diagram for a 3-stage solid-liquid separation process to remove and concentrate solids

9.6 Process Flow Diagrams

As details emerge the block diagram becomes a process flow diagram, or process flow sheet. Figure 9.5 is a flow diagram of the sort that is useful in brochures for visitors to a facility. It shows all process equipment connected into a complete system. Equipment used to move the material (pumps, etc.) and to heat and cool materials are shown. The convention is that material enters on the left and leaves on the right and, generally, gas streams are at the top, liquid streams are in the middle, and solid streams are at the bottom. Details like flow or quantity, composition, and temperature are indicated, usually in an accompanying table.

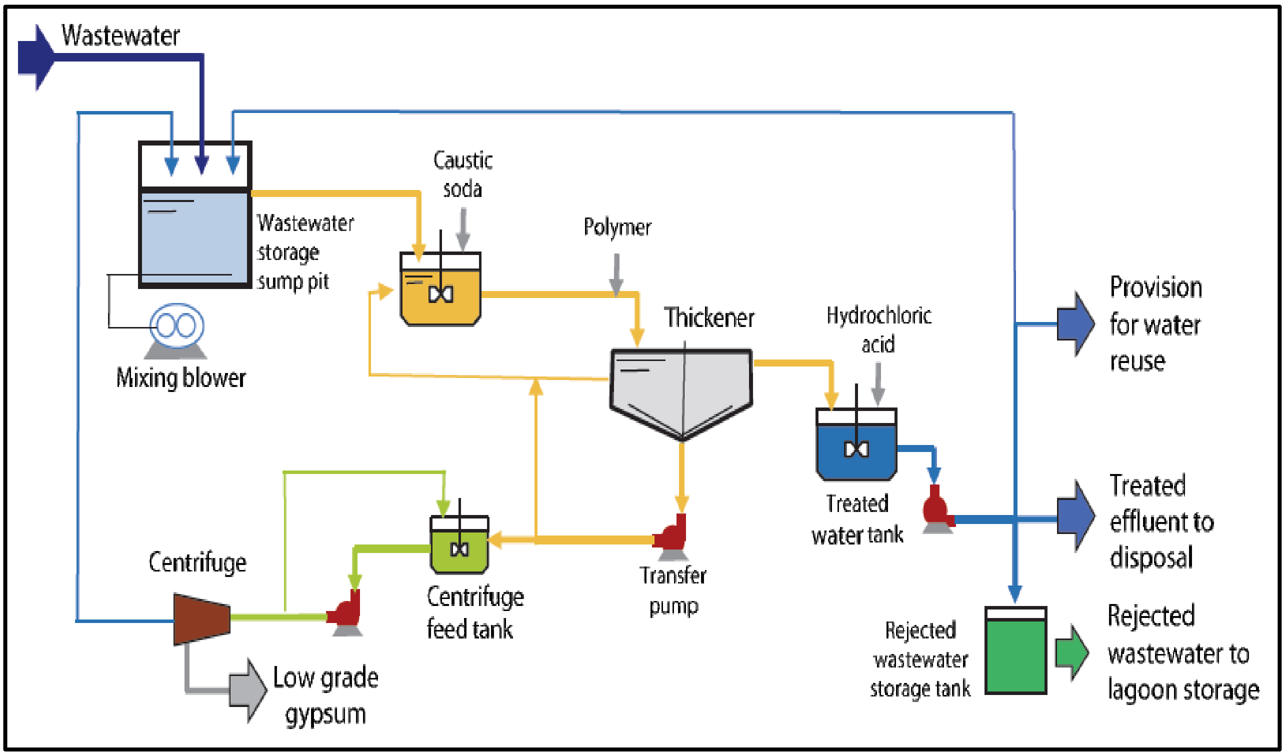

Figure 9.5: Process flow diagram without the details that are shown on the engineering process flow diagram

9.7 Process and Instrumentation Diagrams

The process flow diagram shows less information than a *piping and instrumentation diagram* (P&ID). Figure 9.6 is a simple P&ID. There are two control loops. Loop 100 is for metering soda ash and loop 101 is for pH control by the addition of phosphoric acid. There is a standard system for lines, icons for valves and other elements, and nomenclature for tag names. All tag names in a loop have the same number. Tag names usually have two or more letters. The first letter indicates what is being measured, transmitted or controlled. The second letter indicates the function of the mechanical or electrical device.

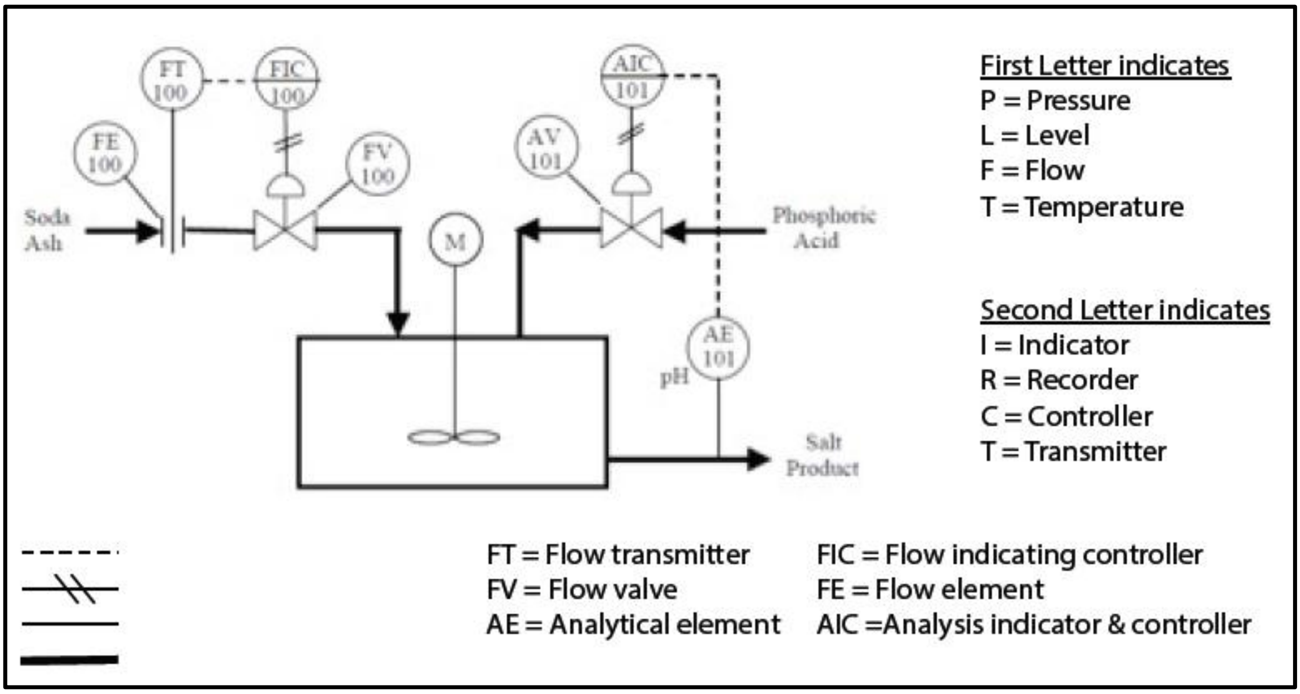

Figure 9.6: P&ID showing simples control loops of reactor

9.8 Conclusion

This has been an overview of the design process, from the initial concepts that are sketched out in block diagrams (some designers call these cartoons) through to the detailed final design. The analysis of material and energy flow in this book will be done with block diagrams and simplified process flow diagrams. Cost estimates are needed in preliminary design to assess financial feasibility and to compare different ideas. More detailed designs with more accurate cost estimates are needed later for client consultations. Finally, detailed designs and cost estimates are needed to arrange budgets and financing. The accuracy of these estimates may be ±25% at the preliminary stage and ±5% for the detailed design. Our interest lies in the early stages of design. These are the most creative and they offer the best possibilities to be innovative with pollution prevention and pollution control. The information that is available for making preliminary cost estimates comes entirely from process flow diagrams and material and energy balances. These are the fundamental tools and the focus of the next few chapters.

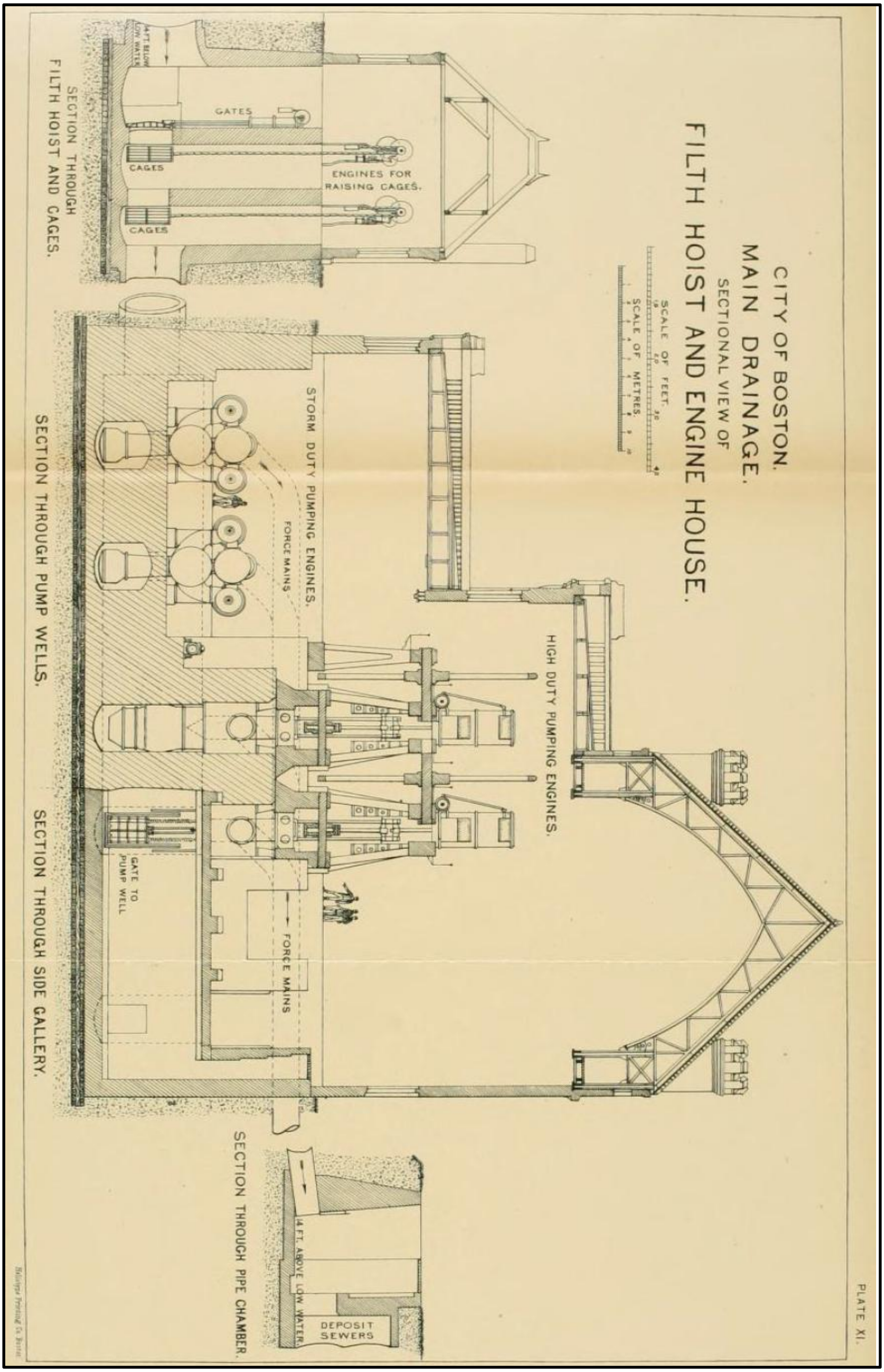

Figure 9.7: Historic design drawing: Side view of the Calf Pasture Pumping Station in Boston (Clarke 1888)