CHAPTER 4: System design

INTRODUCTION

The engineering design is the second stage in irrigation planning. The first stage is the consideration of the crop water requirements, the type of soil, the climate, the water quality and the irrigation scheduling. The water supply conditions, the availability of electricity and the field topography also need to be considered. The economic considerations, the labour and the know-how also need to be taken into account. The irrigation system is selected after a thorough evaluation of the above data and the computation of the system's flow, the irrigation dose, the duration of application and the irrigation interval.

Once the design has been completed, a detailed list of all the equipment needed for the installation of the system must be prepared with full descriptions, standards and specifications for every item.

SYSTEM DESIGN

The engineering and hydraulic design procedure is almost the same in all kinds of pressurized irrigation systems. It consists of a series of interlinked calculations. The various stages are outline below.

Selection of the water emitter (sprinkler, dripper, minisprinkler, bubbler, hose, etc.) according to the crop, irrigation method and requirements:

- type, flow rate, operating pressure, diameter coverage;
- spacing and number per lateral line.

DESIGN OF THE LATERALS

- length, direction, spacing and total number of lateral lines (in solid systems) or lateral positions (in semi-permanent installations);
- flow of the lateral = number of emitters per lateral *x* emitter flow rate;
- number of laterals operating simultaneously = system flow/flow of lateral;
- number of shifts to complete one irrigation = total number of lateral lines or positions ÷ number of laterals operating simultaneously;

- Duration of application = irrigation dose in millimetres ÷ application rate in millimetres per hour, or irrigation dose in cubic metres ÷ system flow in cubic metres per hour.

DETERMINATION OF THE SIZE OF THE PIPELINES

Lateral lines

It is important to understand the water emitter's functions and principle of operation before commencing the design process. One of the main characteristics of all types of emitters is the relationship between flow rate and operating pressure, which is usually expressed by the empirical formula:

$$q = kdH\ *$$

where ***q*** is the emitter discharge, ***k*** and ***d*** are coefficients (constants), ***H*** is the pressure at the emitter and ***** is an exponent characterized by the emitter flow regime and the flow rate curve as a function of the pressure.

The lower the value of *, the less the influence of pressure variations on the emitter flow rate along the lateral line. Most of the water emitter flow regime is fully turbulent with an exponent value equal to 0.5. Thus, the difference in discharge is half the difference in pressure, when the ratio of the two different pressures is < 1.3/1.0.

In order to ensure a high uniformity of water application over the field, the differences in the discharge of the emitters should be kept to the minimum possible and in no case exceed 10 percent. These criteria were established by J. Christiansen for sprinklers and are now applied in all pressurized systems. As a general rule, the maximum permissible difference in pressure between any two emitters in operation should be no more than 20 percent. The lateral lines with emitters must be of a size that does not allow a loss of head (pressure) due to friction of more than 20 percent.

The loss of head due to friction (friction losses) in lateral pipes is taken from a graph or a table. The reading is usually given as loss of head of water in metres or feet per 100 m or 100 ft of pipe. For example, in a 50 mm quick coupling sprinkler lateral pipe with a 15 m^3/h flow, the friction losses are 7 percent. If the length of the lateral is 120 m, the friction losses are: 7/100 120 = 8.4 m. However, this figure is for the total flow of 15 m^3/h running the whole length of lateral. Thus, it is not the true figure as the flow is distributed en route through the emitters. In order to compute the actual losses the above figure is multiplied by Christiansen's reduction coefficient, F, to compensate for the water delivered along the lateral line. The F values depend on the number of the outlets uniformly spaced along the pipeline (Table 4.1).

Three different series of F values exist corresponding to the Q exponent (m) of the three main friction loss formulas: Hazen Williams, 1.85; Scobey, 1.9; and Darcy Weisbach, 2.0. Moreover, lower values are taken if the distance of the first outlet is half the spacing of the outlets, etc. However, the differences between the various F values are almost negligible.

TABLE 4.1 - F factor for multiple outlets

Number of outlets	F value (m = 2.0)	Number of outlets	F value (m = 2.0)
1	1.0	12	0.376
2	0.62	15	0.367
3	0.52	20	0.360
4	0.47	24	0.355
5	0.44	28	0.351
6	0.42	30	0.350
7	0.41	40	0.345
8	0.40	50	0.343
9	0.39	100	0.338
10	0.385	>	0.333

Assuming that in the above example there are ten emitters (in this case sprinklers) on the lateral, the F value is 0.4. Then, in a 50 mm quick coupling lateral, 120 m long, with a flow of 15 m^3/h, with 10 sprinklers of 1.5 m^3/h at 2.0 bars, the friction losses are: 7/100 *x* 120 *x* 0.4 = 3.36 m head of water. This figure must not exceed the maximum permissible, which is 20 percent of the emitter's average operating pressure, i.e. 2.0 bars *x* 0.20 = 0.4 bars (4 m) on level ground. Where the lateral slopes downwards, the difference in elevation is added to the maximum permissible loss of pressure. Similarly, it is deducted where the lateral slopes upwards.

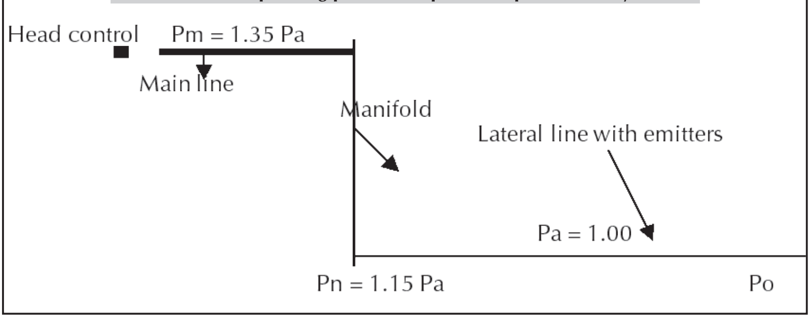
Due to the multiplicity of emitters with variable flow regimes and other factors affecting the pressure/discharge relation along the laterals in the field, such as local minor losses that occur at the connection of the emitters on small-sized pipes and temperature fluctuations, the manufacturers should always provide charts for the optimum length of emitter laterals, based on the size of pipe, emitter spacing, operating pressure, flow rate and slope.

Manifolds, submain and main pipelines

On the manifolds, whether these pipelines are the submains or the mains as well, a number of laterals are fed simultaneously. The flow of the line is distributed en route, as in the laterals with the emitters. Consequently, when computing the friction losses, Christiansen's reduction coefficient, F, is also considered. Example: 120 m of 75 mm HDPE, 6 bars, manifold line, 16.3 m^3/h, 6 laterals operating simultaneously; the friction loss under full flow is 3.3 percent, i.e. 4.0 m *x* 0.42 = 1.7 m approximately.

The mains, submains and all hydrants are selected in such sizes that the friction losses do not exceed approximately 15 percent of the total dynamic head required at the beginning of the system's piped network. On level ground, these friction losses amount to about 20 percent of the emitter's fixed operating pressure. This is a practical rule for all pressurized systems to achieve uniform pressure conditions and water distribution at any point of the systems. Figure 4.1 below should not be confused with or related in any way to the maximum permissible friction losses along the laterals.

FIGURE 4.1 - Operating pressure required for pressurized systems.



In the above figure, Pa is the average emitter pressure, or fixed pressure taken from the catalogue; Pn is the lateral inlet pressure; Po = 0.95 Pa is the distal end emitter pressure; and Pm is the pressure at the inlet of the main line.

Pn - Po = 0.20 Pa;
Po = Pn ÷ 1.21;
Pn = 1.15 Pa;
Pm = 1.35 Pa.

The friction loss in a lateral with emitters is very high at the beginning and drops rapidly after the first few outlets and then more gradually toward the end of the line. In the upper one-fourth of the lateral the friction loss is approximately 75 percent of the total. Another important element is the flow velocity in the mains, submains and hydrants. This value should always be kept below 1.7 m/s in plastic tubes and a maximum of 2 m/s in other pipes (steel, aluminium, etc.). From the flow velocity formula, V = Q/A, the pipe inside diameter is determined for a given flow:

$$diameter(mm) = \sqrt{\frac{Qm^3/hr}{V(m/s)}} \times 18.8$$

HEAD CONTROL

The component parts of the head control and their size are in accordance with the system requirements. In micro-irrigation systems the units are complete with filters and fertilizer injectors, while in sprinkler and hose irrigation systems the head controls are simple with the minimum of equipment. The friction losses in the various component parts vary accordingly from 3 to 10 m.

The friction loss formulas are empirical and include many variables and correction factors. In calculating the pipe friction losses from equations, extensive practical experience is needed. In view of the fact that great accuracy is not possible due to the unpredictable changes in pipe roughness, water viscosity, nozzle wear, clogging, etc., the use of friction loss tables and nomographs is recommended.

TOTAL DYNAMIC HEAD OF THE SYSTEM

The total pressure head or dynamic head required for the normal operation of the system is the sum of the following pressures (Table 4.2):

TABLE 4.2 - Total pressure head of system

Pressure at the emitter	Metres head
Friction losses in the lateral line	Metres head
Friction losses in the manifold	Metres head
Friction losses in the submains and in the main line	Metres head
Friction losses in the valves and pipe fittings and minor losses (usually up to 15 percent of the total losses in the pipes)	Metres head
Difference in elevation (plus or minus)	Metres head
Loss of pressure in the head control	Metres head
Total pressure head of system	**Metres head**

TOTAL DYNAMIC HEAD OF THE PUMPING UNIT

This is the sum of the system's total head plus the pumping lift. The brake horsepower formula is:

$$BHP = \frac{Q \times TDH}{270 \times e1 \times e2}$$

where ***Q*** is the flow capacity in cubic metres per hour, ***TDH*** is expressed in metres, ***e1*** is the pump efficiency (fraction), ***e2*** is the driving efficiency (fraction), and 270 is a constant for metric units.

- Pump efficiency: 0.5–0.8;
- Electric motor efficiency: 0.7–0.9;
- Diesel engine efficiency: 0.5–0.75.

The overall pumping efficiency under field conditions ranges accordingly from 0.35 in engine driven units to 0.50 in motor driven pumps. Higher efficiencies are not realistic.