Micro Irrigation Engineering
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Lecture – 56
Economic Analysis of MIS (Part 2)

Hello, participants. I invite you to Lecture 56 of Micro Irrigation Engineering subject. Lecture 56 is on Economic Analysis of Micro Irrigation System, Part 2. On the same topic, Part 1 in Lecture 54, we discussed about different terminologies which are important for economic evaluation where different types of cost terms it comes, benefit cost analysis, net present worth, how to compute, so different expressions which are involved to estimate we discussed in previous lecture.

In this lecture, we are going to discuss on the critical flow criteria, for selection of micro irrigation pipes. We will be dealing with optimal flow and this concept has been utilized considering a hypothetical example for say sector area in order to make you understand how optimal flow criteria can be used to select the particular size of pipeline.

In theoretical consideration before I speak about different terms involved, let us try to first revise the terms which we discussed in the design part. In design, we estimated head loss due to friction. Our aim was to reduce the head loss due to friction. So, we are considering these size of the pipeline in such a way whether it is a main pipeline of micro irrigation system, whether it is a sub main pipeline of micro irrigation system or it is a lateral pipeline.

So, our aim was to reduce the head loss due to friction and other losses, which takes place in the pipeline. So, if we are considering say one particular pipe size and we find that head loss due to friction is some quantity in meter. And then, we are taking another which is higher than the previous one. So, question comes, what should be the size of the pipeline one should select?

So, one always feels that yes if I am going for the larger size then economics come into picture that whether we are taking a new higher size pipeline, then economics is important.

Now, if we are considering this shorter pipeline means head loss due to friction will increase. But, it is in the permissible level. But, the amount of energy required because that is a variable cost. It will continue to every time when you are operating, the variable cost will increase. So, that is a cost which will be recurring almost daily as and when we operate the pump. So, these 2 costs which are there one is due to the size of the pipeline. Other cost is due to operational that is variable cost, so, operational cost. So, these 2 things are to be considered what size of the pipeline should be considered.

So, life, this term which has come, it is a life cycle costing technique. It has been used to optimize the pipe diameter to determine the optimal flow between 2 pipe sizes, 2 adjacent pipe sizes or 2 pipe sizes which are just one is say 12 millimeter another one is 16 millimeter for the case of lateral. So, whether should I go for 12 millimeter? I should go for 16 millimeter. That is the 2 adjacent pipe means.

Now, when we talk of the economic optimization part, we need to consider several factors. That is the size, market price and then, what is the application rate? And then, how many hours the system in a year this pump will operate? And then, what is the overall efficiency of the system? All these things will come. The important term here it will be used in all throughout my presentation is optimal flow.

What is this optimal flow? It is the flow rate at which the total annual cost between 2 adjacent pipes can be equated. Means, we are equating these 2 pipes. And then, seeing that which pipeline will be giving best flow rate which will be useful for us. So, these 2 pipeline values they will be used and then in order to find out the optimal flow between the 2 diameters.

Now, if we are considering let us say D1 and D2 are the 2 pipe sizes and their respective cost per unit length is given as a C1, and C2 that these terms we will use in further. But, let us come to what is the capital recovery factor? This is a common terminology when we are making the estimation. So, capital recovery factor it is a function of prevailing interest rate in a given period of time.

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

So, n is the number of life period, number of years. And then, i is the interest rate in percentage.

When we are talking about the total cost to estimate to we are interested about the finding out the critical flow. So, critical flow criteria means we will be equating these 2 terms. That is one total cost is the annual cost of the pipe and annual cost of pumping. One it is written to refers to the diameter D1. Now, similarly, for other diameter D 2, TAC 2 can be computed.

$TAC_1 = (AC_1)_{pipe} + (AC_1)_{pump}$

Now, as I told you that according to this criteria, these 2 cost, one is the cost of the pump and of the diameter D 1 and cost of pumping by using the pipe diameter, A1 is equated with the annual cost of the pipe having diameter D 2. And then, corresponding what is the annual cost of pumping for the diameter D 2. So, these are equated.

$(AC_1)_{pipe} + (AC_1)_{pump} = (AC_2)_{pipe} + (AC_2)_{pump}$

Now, these annual cost is put up in the form of fixed cost and operating cost.

$(FC_1)_{pipe} + (OC_1)_{pump} = (FC_2)_{pipe} + (OC_2)_{pump}$

The term in this subscript 1 refers to the diameter D 1 and subscript 2 refers to the diameter D 2. So, FC 1, FC 2 these are the fixed cost and operating cost.

Now, this can be given that means fixed cost and operating cost it is brought in terms of the horsepower requirement multiplied by the cost of the water horsepower. So, this part when operating cost it is brought, it is brought in terms of the economics value. So, this can be given as means this is a standard formula the horsepower, horsepower can be computed by this one.

$$(FC1)_{pipe} + \frac{(Q_u H_1)C_{WHP}}{75\times3600} = (FC2)_{pipe} + \frac{(Q_u H_2)}{75\times3600}$$

That is the flow rate multiplied by the head. So, this H 1 and H 2, these are the head losses or head we can say total head of the pipeline. And, the diameters are D 1 and D 2. And this is simply discharge of the unit that is the flow into the system. And then, this is a unit constant it is given in the liter per hour. So, this way we are putting it the equating this part.

The cost of the horsepower is given by the energy cost multiplied by the horsepower operating horsepower per unit. Means, in a year, how many hours the pump will operate divided by the pumping efficiency?

$$C_{WHP} = \frac{H_0 C_0}{E_f}$$

So, when we are using this particular equation, equation 5 is written in this form. This can be written as

$$\frac{Q_u}{75\times3600}\left(H_1 - H_2\right)C_{WHP} = DF$$

And therefore

$$\left(H_1 - H_2\right) = \frac{DF\ x\ 75\ x\ 3600}{C_{WHP}\times Q_u}$$

Where,

H_1 and H_2 = head losses due to friction in pipes of diameter D_1 and D_2 respectively

Q_u = total flow into the unit ($L\ h^{-1}$)

DF = difference in annual fixed cost per unit length of pipes D_1 and D_2 (Rs.)

C_{WHP} = cost of water horse power (Rs.)

H_o = hours operating of system per year

C_o = energy cost (Rs. / bhp h)

E_f = overall pumping efficiency

This is the difference means we are equating this part. So, this has come as H 1 minus H 2 multiplied by the cost of the water horsepower is equal to the difference in annual fixed cost. Difference in the annual fixed cost means when we are considering D 1 and D 2. So, this way we are getting the expression. What is the means expression we can get in terms of H 1 minus H 2? That is the head loss when we are considering 2 diameters in terms of the cost unit.

Now, this particular equation, which we have got equation to this head loss. So, head loss is equated. That is Hf. Hf is equated by using the appropriate friction factor depending on the type of a flow regime. Now, this H 1 and H 2 that difference is written in the modified form of the Darcy Weisbach equation.

$H_f = 6.3755 \, f \, L \, Q^2 \, D^{-5}$

Where,

H_f = frictional head loss (m)

f = Darcy's frictional factor

L = length of pipe (m)

Q = flow rate ($L \, h^{-1}$)

D = internal diameter of pipe (mm)

We already discussed this particular when we were discussing about flow through pipes.

So, Darcy Weisbach equation as well as Hazen William's equation we have discussed in prior. And then, if you remember this simply Darcy Weisbach equation is Hf equal to f L V square by 2gD. So, that V square term is brought in terms of the means Q square by A square. And, A square can be written as pi D square by 4. So, this is the modified form of that component. It has been brought means that equation it is in this form it is written. Now, that Hf is substituted in this. Then, there is equation which we will use for finding out this f. This is a frictional factor f, will be substituted by using the appropriate equation for the Reynolds number.

So, let me just show you that Reynolds number is given by the 4Q divided by this k. k is a constant that is equal to 3600 because this unit is here liter per hour. And, this eta is this kinematic viscosity and D is the diameter of pipeline. So, this way it is given. And then, here we know if the flow is in the turbulent range means fully turbulent range when we are talking. So, Reynolds number is between 4,000 and 10,000.

So, this particular component we are going to introduce. So, for turbulent flow condition, we are putting the appropriate value in the equation 8. So, equation 9, 10, 11 is substituted in equation 8. So, what is that equation 8? I am just bringing you back. This was the equation 8. So, this is Hf practically. So, this we are putting H f in terms of the Darcy Weisbach equation. So, this equation we are putting it. And then, we have substituted 10 and 11. By substituting the appropriate value of the Reynolds number and equation comes in this form

$$0.465 \times Q_c^{1.75}\left[\frac{1}{D_1^{4.75}} - \frac{1}{D_2^{4.75}}\right] = \frac{DF\ x\ 75\ x\ 3600}{Q_u\ C_{WHP}}$$

So, from there, actually, this equation it has come from equation 8.

Now, assuming that the flow through the unit is equal to Qu equal to Qc that the flow through the system, equal to critical flow. That particular equation 12 can be converted in this particular form for calculating the optimal flow between the adjacent diameters. That is D1 and D 2. Adjacent diameter, as I told you that, what is the next diameter? If not the previous diameter, what is the next diameter?

So, normally say when we are considering the main pipeline, so, 63 millimeter is the let us say 63 millimeter is the internal diameter of the pipeline. So, next available diameter is 75 millimeter. So, comparison is made between the next adjacent diameter or 75, 75 millimeter is nothing but 3 inch pipe size. So, it can be 3 inch pipe size or it can be 3 and half inch. That is 90 millimeter. So, like this, we are using different.

$$Q_c = \left[\frac{\frac{k_1}{k_2}}{\frac{1}{D_1^{4.75}} - \frac{1}{D_2^{4.75}}}\right]^{0.3636}$$

So, Qc is converted in this form by using the equation 12 and where it is coming in the form of the ratio of k1 by k2. And then, 1 minus D1 to the power 4.75 minus 1 by D2 to the power 4.75 where k1 is this expression. k1 is to be obtained by using this expression.

$$k_1 = \frac{DF \times 75 \times 3600}{C_{WHP}}$$

And, for a given set of condition, k2 becomes 0.465. So, optimal flow between 2 means adjacent pipe diameter can be obtained by using the data on available pipe sizes which are available in the market. Their cost, applicable bank interest rate, cost of the energy, hours of operation per year, and overall pumping efficiency. So, this way it can be used in finding out the optimal flow.

So, the equation 13 can be written in a generalized form. That is your optimal flow rate Qc can be given by this expression.

$$Q_c = \left[\frac{\frac{k_1}{k_2}}{\frac{1}{D_1^{a}} - \frac{1}{D_2^{a}}}\right]^{b}$$

And if means, there are 2 cases it has been considered. This is a generalized form of the equation where if I am using say Darcy Weisbach equation, it has a provision to estimate friction factor f when the flow is laminar, transitional as well as for turbulent flow.

Whereas, Hazen Williams equation, it is used only for a specific case. Means, there is the value of f, there is no provision to change. So, normally, this is for turbulent flow case. Now, here the value of k2 is estimated when f is taken as for laminar flow case, so, k 2 is obtained from using the previous expression and then corresponding a and b which is there in the expression.

Those corresponding values of a, here, a is the exponent and b is obtained for different you know f values and as well as for the C equal to 150. So, having got this value, we can develop a curve that I will discuss.

So, optimal flows in drip diameter where it requires means the information related to 2 adjacent pipe sizes, annual interest rate, how many means operating hours in a year. Then, what is the life of the pipes? That is what for PVC pipeline and plastic pipeline, normally, it is 40 years it is taken, an overall pumping efficiency as well as energy cost. So, if it is a main pipeline, it is of 25 to 40 years. Normally, 25 years people take. But, maximum it is given as I was telling that Thompson table in the previous class which I told you that when we were estimating the depreciation. So, there it was considered as a 40 years but 25 years is the period it can be taken and then number of operating hours and year. So, this way it is calculated.

Now, life period of pipes vary based on the pipe material. Hence, suitable value for the life period is considered on what is the type of pipe material which we are using in the analysis. Now, details of the pipe sizes and the unit cost is of course these costs which are available. These costs are very old, pretty old means, it is considered based on the price which were prevailing price of 2006 by Dr. Yella Reddy in his PhD research work. He did PhD research work at IIT Kharagpur in the Department of Agriculture and Food Engineering with me. So, same data, which I am producing here in the year 2006 and same data, it has been used here.

So, given these data and the pipe sizes, the critical flow values, which were obtained and then a graph is plotted. When we are considering the life period of course in this particular case, we are considering 10 years. And then the annual operating hours is 2000 hours. Annual interest rate, a general interest rate it is taken as 12%. Pumping efficiency is 65%. And, cost of energy is 1 rupee per bhp hours.

So, you can see here how it is plotted. It is plotted for different successive pipeline and the critical flow rate. So, this particular thing means this particular curve when it is plotted it is coinciding when we are considering the turbulent flow case. Means, we have taken a turbulent flow case and for this turbulent flow case what we find that the Hazen Williams equation as well as the Darcy Weisbach equation, it is giving the same values. Means, they are not same value, but almost it is coinciding.

So, optimal flows rates were obtained by considering the successive pipes under turbulent flow and fully turbulent range for the Darcy Weisbach equation and also with the Hazen Williams equation when we are considering the constant C for the pipeline is 150.

So, when we consider the Darcy Weisbach equation for the turbulent flow optimal flow for the pipe size combination of 40 to 50 millimeter is we are getting the flow rate as 5,085 liter per hour. And, when we consider say larger size pipeline, it is 75 to 90, we are getting 21,049 liter per hour. Now, these values indicate the flow rate at which the pipe has to be means one can means the flow rates at which the pipe sizes can be changed.

For example, when we are taking if the flow rate is expected in pipeline in between 13,500 to this range, then 75 millimeter pipe size advisable. Now, when the flow rate it exceeds 21,049 liter per hour, then one should use the 90 millimeter pipe size. So, in this range, the smaller pipeline can be taken but when it exceeds the value than the higher size, it is recommended when we are considering the optimal flow criteria. So, optimal flow criteria provides a useful information for selecting the pipe size of the pressurized irrigation system.

Now, in order to use this economic means this particular criteria, so, a hypothetical example has been taken, where the drip system has been considered for 6 hectare Banana crop. And then, the data which has been used for this study, spacing is considered as 2 meter by 2 meter and this 6 hectare area it has a length of 400 meter and width of 150 meter. It is a flat terrain.

We have considered it is a medium textured sandy loam soil. And then, the peak evapotranspiration rate is 9.75 millimeter per day of course, this is a considerable very high value normally. This evaporation rate in our country it is rare, but it is a hypothetical question that were to make you understand about this particular thing. So, this is not exactly it is happening in our case.

Normally in our country, the evaporation rate it is varying from maximum it goes up to 6 to 7 millimeter per day. And well is a source, means, well, it is taken as a groundwater and static water level is 8 meter. Emission uniformity, it considered as a 90%. And then there is a limiting velocity. This is the value where maximum velocity it is recommended by American Society of Agriculture Engineers that in the pipe flow, particularly for drip irrigation pipeline, the velocity should not exceed more than 1.5 meter per second.

The other cases here you can see here we are we have taken the lateral pipeline, sub main pipeline, main pipeline of these sizes and then their corresponding. So, lateral pipeline, it is given as a Dl 10, Dl 12, and Dl 16. Dl means diameter of lateral pipeline of 10 millimeter, 12 millimeter, 16 millimeter. Though cost it is less, now, this prevailing cost at present means these are the cost which were assumed. Means, these were taken 15 years back. So, these costs are considerably very low, but it will go high. Then, in case of sub main pipeline, the pipe sizes were the 50 millimeter, 40 millimeter, then 50 millimeter, 63 millimeter. And main pipeline, it has been taken 75 and 90 millimeter.

And as I told you that this is the field size of 400 meter by 150 millimeter, which is 6 hectare area. And, there is 1 dripper of 4 liter per capacity to each plant it has been given. And, these are other information the total number of plant for 6 hectare area is 14,800. And then, one row it is kept in the middle so, that easy operation for operating the subunits can be made. Means, suppose it is manually operated system then one has to go and operate the valve etcetera. Now, considering all the 14,800 plants and 4 liters of water per hour, so, the discharge requirement is 59,200 liter per hour. It is also considered that the flow in the main pipeline when we are considering this discharge, the flow velocity it is coming 2.59 meter per second, which is higher than the required.

So, we need to take consider such velocity which is given as suggested by American Society of Agricultural Engineer. And, from the market available, these are sizes it has been considered. And, in order to means not to operate all the lateral lines. So, there are arrangement it has been made that it can be considered too. So, means there are 2 irrigation plan it has been suggested. So, half of the field it will there.

So, you can see here the layout it has been made. So, here, layout it goes like this. This is the source of water. And, from the source of water, there is a pump. And, pump is connected with the main pipeline. So, pipeline goes from the middle of the field. And then, these are the sub main unit. And then, with these sub main units, the lateral pipelines are attached. Total, you can see here there are total 8 subunits. Means, there are total 8 plots or 8 subunits.

So, 1, 2, 3, 4 on this side and then 5, 6, 7, 8 on this side and this particular sub main which is there it is supplying water up to this part. So, there will be here valve, it will be closed when we are going to apply water to the subunit. This particular plot 5 or we will be again I mean so, all these subunits are given valves to operate. So, this is the arrangement, the other details are available in the problem.

Now, as there are 2 irrigation plan which has been suggested. One irrigation plan, that irrigating subunits 1, 2, 3, 4 in one shift. So, from here this is the middle part. And then these are the 4 subunits being irrigated and then 5, 6, 7, 8 is another shift. Like this there are the other one is giving irrigation to 1, 2, 7, 8, means this part and 3, 4, 5, 6 in the another shift.

So, there could be 2 arrangements. And, optimal flow rates are computed for successive pipes. And then these are the data which has been considered. That is the life period is 10 years, interest rate 12% and these are the other data which already I have told you. So, in order to study the effect of time of operation on optimal flow, the analysis has been made by considering the time of operation in a year. That is 500 to 2,500 by taking the interval of 500 hours.

So, here, we can see that these are the operating hours. And, when we are considering the optimal flows, estimated or given in the table where this indicate the flow rate at which the pipe diameters can be changed from lower to higher or the consequent pipe size of 63 millimeter to 75 millimeter and 75 to 90 millimeter. So, this way, we are getting the values.

And then, these values at which the optimal flows are obtained. So, what we say let us say that it is the when we are considering the 2,000 hours of operation, the pipe size required to be changed from 63 millimeter to 75 millimeter when flow in the network exceeds 13,520 liter per hour. Similarly, the pipe size has to be changed from 75 to 90 millimeter means particularly at the flow rate when it exceeds 21,048 liter per hour. Here, this has been converted to liter per second. Means, liter per hour is converted to liter per second.

So, design of main pipeline means there is another criteria. That was from the optimal flow criteria and when we are making the velocity as the criteria, so, means the limiting velocity is taken as 1.5 meter per second as per the recommendation of ASAE. So, flow velocity in the main pipeline for different flow rates. So, when we are considering 63 millimeter pipe size, so, we will find out the area under this pipeline.

And when we have got different expected flow rate, so, we will get different velocities for the different sizes of the pipeline. 63 millimeter pipeline, so, this we are getting 0.66 meter per second. And then, when we go for the higher flow rate, the velocity it comes to this one. Now, when we go for the further higher flow rate, we find that 63 millimeter pipeline it will be exceeding the velocity limit of 1.5 millimeter per second. Then, one should think of another pipe size that would be the higher pipe size. Similarly, for the other pipelines. So, these are the values one can select by considering the velocity criteria.

So, in calculating the pipe sizes for the maximum flow expected to each zone, has been considered. We are assuming means there are some other assumption which is given that the length of pipeline, when we are connecting with the source of power, is 10 meter. And, the 2 irrigation plan which I have already discussed you how these to be operated in shift 1 and shift 2.

And, when we are using the irrigation plan say 1, the requirements of the pipe were 100 meter pipe of 63 millimeter, then 100 meter pipe size of 75 millimeter, 110 meter of the 90 millimeter pipe size means considering when we are using the optimal flow criteria. And, with irrigation plan 2, when we are considering, so, these are the dimensions which we are getting for these 2 pipe means your other plan, so, though estimates were also based on the taking the each segment.

Now, estimates are made for the irrigation plan assuming 3, 4, 5, 6 subunits are to be irrigated in one shift. So, the segment of pipe carrying water to the subunit 4, 5 should carry this much amount of flow. That is 14,800 liter and should be of this diameter. I mean 100 meter long pipeline of 75 millimeter. Then, the entire area for 3, 4, 5, 6, these are the pipeline which has been suggested based on the optimal flow criteria when we are using.

And accordingly, the cost were estimated. And then, what we find? The cost of the main pipeline when we are using I 1 plan, and I 2 plan what we find that the there is a net saving in the rupees of 2,770 by adopting ,using the plan I 1 over I 2. So, I 1 is more successful when we are taking the optimal flow criteria. Now, this indicate the selection of irrigation pipe is an important aspect to optimize the pipe requirement.

Then, the estimates which has been made for the different length of the pipeline on the basis of optimal flow criteria and velocity criteria. We have taken both the criteria when we are comparing. So, what we find that the, this is the combination when we are using for 63 millimeter pipeline of 100 meters, 75 millimeter of 100 meter, 90 mi. So, this way is the total cost it comes to 1,242. Whereas, velocity criteria it is giving 9282 when for the irrigation plan 1. Similarly, in case of irrigation plan 2, the total cost come to 14,000. And, in this case, it is coming 13,722 rupees.

So, this way one can compare. So, comparison is made taking the different pipe sizes and also by using the 2 different criteria. That is optimal flow criteria and velocity flow criteria, so, maximum velocity criteria. So, what we are finding that the frictional head loss in the main pipeline is estimated by considering the total flow which is taking place in each zone.

Annual cost of the mainline was more for the larger pipe size and however, the annual operating cost it becomes less because the frictional cost or energy requirement is less. So, total annual cost considered for the purpose of comparison the by pipe size combination with the lower annual costs are better for selection. In all irrigation plans the optimal flow criteria proves to be more economical.

Now, in calculating the horsepower requirement, constant of 2 meter of head in accessories and 8 meter for the suction head which is given in the question that has been added. And then, we are taking the 10 meter as the pressure head to operate the drippers. And, total head requirement estimated to be 20 plus frictional losses in the main pipeline.

So, in all the cases, optimal flow criteria proves to be requiring less horsepower to operate prime mover than uniform size of 63 and 75 millimeter size. So, use of uniform size of D 90 would need less prime mover size, but annual cost of the pipe would be much higher than those selected with optimal flow criteria. So, this shows that optimal flow criteria should be the basis for pipe selection, in selection of mainline, in drip irrigation system design.

So, this is the comparison which I have told you that when we are considering the optimal flow criteria, the energy cost and then annual fixed cost, the horsepower requirement of the prime mover. So, this is all it is lesser than the velocity flow, velocity criteria, when we are taking it. So, it is you can see here this is 2,961.5 rupees where this comes to 2,999.5 rupees.

So, like this here also you can see it is lesser than the velocity, maximum velocity criteria. So, this is giving optimal result.

So, let us summarize this part the optimal flow criteria and Life Cycle Costing technique have been used for the development of equation for finding out the economical pipe size. The model equation developed was based on both economic as well as hydraulic consideration. It estimate the flow rate at which the designers should change from one size to another pipe size. We have taken an example for implementing in 6 hectare area for the comparison purpose. And then, we found that the annual cost was lowest when we are using the optimal flow criteria. In all the irrigation plan optimal flow criteria was found to be economical.

So, this is the summary part which I told. And then, in the forthcoming lecture, we will again discuss about the economic analysis of micro irrigation system. That will be Part 3 in continuation.

You may refer these references, research paper which has been published in the journal particularly on this aspect. So, you may refer this paper and then also you can refer internet for this purpose, thank you very much.