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CENTRALIZED CONTROL EQUIPMENT OF IKUTA WATER PURIFICATION WORKS IN KAWASAKI

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I. INTRODUCTION

The Ikuta Water Purification Works of the Kawasaki City Water Department has a planned standard water treatment capacity per day of 400,000 m^3 (250,000 m^3 of industrial water and 150,000 m^3 of clear water) and is supplied with raw water from the Tama river route of the Kawasaki City water system which consists of the Tama and Sagami routes. The Tama river route raw water from intake to to supply is completely handled by pumping up and supply under pressure. Since it is located far from the users, the costs for water treatment are not economical compared with those for the Sagami route where the natural down flow system is used. Therefore, when water is supplied, the economical Sagami water is given priority, and when there are variations in the water requirements due to seasonal or time changes, convienient adjustments can be made by sending water to or taking it from the Sagami system. Water is taken from the Tama river raw water and sent not only to the distribution areas but also to the Hirama and Nagasawa purification plants. Therefore, the pipelines are complex and many people would be needed for pump control, plant valve control, etc. so that the plant will run smoothly. To avoid this a computer was introduced to achieve complete automation and thus make the plant more economical and safe.

Technical planning for the computer got underway in the autumn of 1968 and in July, 1970, the computer control equipment was delivered to the site. After site adjustments, test runs and operator training, it went into automatic operation in October. Prior to this in 1968, a large scale investigation was carried out concerning the relation the amount of water intake and the change in the water level for one of the wells of the purification works raw water. This investigation yielded valuable data not only for this project but also for general work of this type.

This article describes the computer control and its functions.

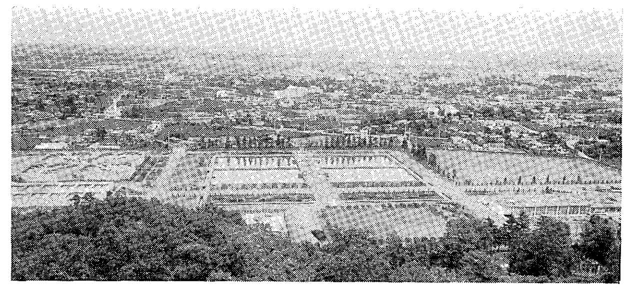


Fig. 1 Bird's-eye view of Ikuta Water Purifications Works

II. OUTLINE OF IKUTA WATER PURIFICATION WORKS

Fig. 1 shows an bird's-eye view of the works.

Site : Ikuta No. 262, Kawasaki
Area : about 171,000 m^2
Water supply : Tama river route (surface water, infiltration water and underground water)
Water removal method : pumps
Treatment method : High speed sedimentation, rapid sand filtration, slow filtration, chlorine purification
Water supply method : supply under pressure by pumps
Operation : centralized automatic remote control and monitoring
Scale : Standard amount of water taken in, treated, and supplied per day { industrial water : 250,000 m^3; clear water : 150,000 m^3 }

As is indicated above, there are three intake routes for the purification plant : Tama river surface water, Tama river infiltration water and underground water. *Fig. 2* shows the intake pump station. *Fig. 3* shows the surface flow pump station.

Water intake from two areas is filtered once through sand, raised from the pump well by the intake pump and supplied to the Ikuta purification works through a supply pipeline under a pressure of 1.8 kg/cm^2.

The three intake pumps are capable of pumping

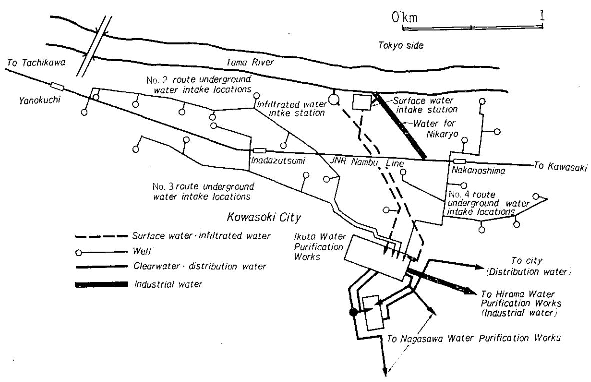


Fig. 2 **Intake pump station**

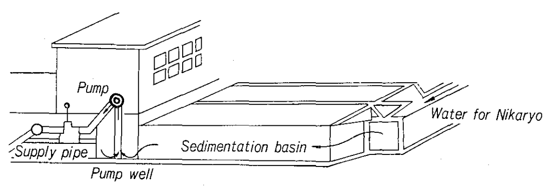


Fig. 3 **Surface flow pump station**

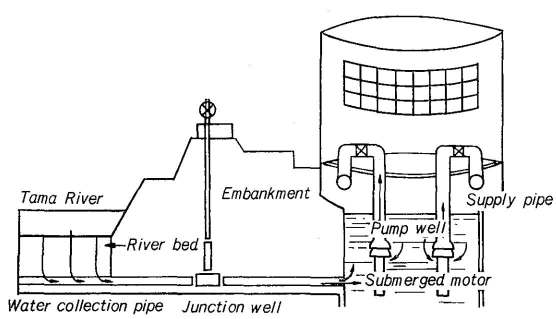


Fig. 4 **Infiltrated water pump station**

up 100,000 m³ of water per day to a height of 18 m. These pumps contain a 250 kW motor.

Fig. 4 shows the infiltration water pump station. Infiltration water is conveyed to the pump well by the collection pipe (diameter: 900 mm, length: approx. 500 m) buried 4 to 6 m deep in the bed of the Tama river. The water is then raised by the motor pump immersed in the water in the pump well and supplied to the purification works.

This pump well is circular with a diameter of 9 m and a depth of 12 m. The intake pump is capable of pumping 10,000 m³ of water per day up to a height of 18 m and there are six of these pumps. These pumps have a 65 kW submerged motor.

Fig. 5 shows the underground water pumping station. The pump well has a diameter of 6 m and a depth of about 15 m, and at one position either inside or outside the well, there are one or two motor pumps. These pumps are capable of pumping 10,000 m³ of water per day up to a height of 18 m and therefore, there are a total of 37 pumps in 22

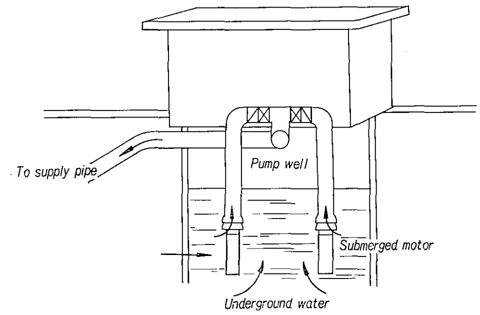


Fig. 5 **Ground water pump station**

locations in the well for the No. 2, No. 3 and No. 4 intake routes.

The surface and infiltration water of the Tama river is led to an accelerator which is shown in *Fig. 15.* Here it is treated with chemicals. There are 4 treatment basins each with a diameter of 31 m and a depth of approx. 10 m. The treatment capacity for each basin is normally 50,000 m³ per day, with a maximum of 75,000 m³ per day. The water treated in these basins is supplied mainly as indutrial water.

The underground water which is pumped up to the pump well is supplied to various locations for various purposes by the supply pumps located in the well. There are 13 of these pumps and each is capable of pumping 50,000 m³ of water per day up to a height of 74 m. Since all of these pumps are remote controlled in the central control room, they are located at appropriate positions underground and they can be operated directly in accordance with the general need to keep the pump filled with water. These pumps are operated by means of 550 kW (750 HP) motors.

III. COMPUTER CONTROL EQUIPMENT CONSTRUCTION

1. Computer Control equipment

Fig. 6 is a block diagram of the computer system.

1) Central processing unit (1)
   FACOM 270–20 (Core 16 kw, Drum 131 kw)
2) Real time controller (1)
3) Input/output unit (1)
   FACOM WRITER F 801 A
4) High speed paper tape read unit (1)
5) High speed paper tape puncher (1)
   FACOM 767 A
6) Typewriter (2)
7) Operation console
8) Relay panel
9) Date transmission equipment

2. Real time controller input/output points

Interrupt input	64 points
Analag input	128 points
Pulse input	2 points

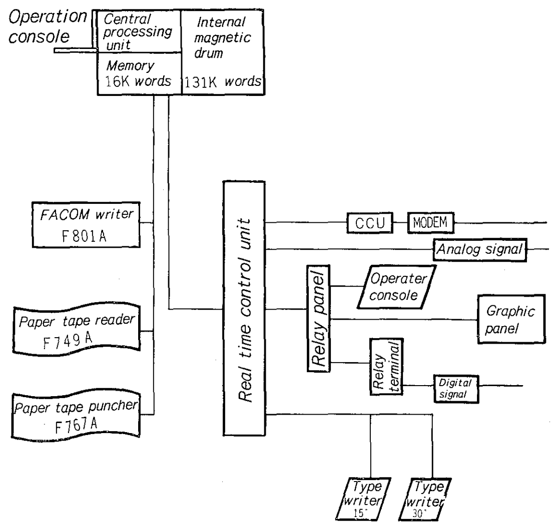


Fig. 6 Block diagram of computer system

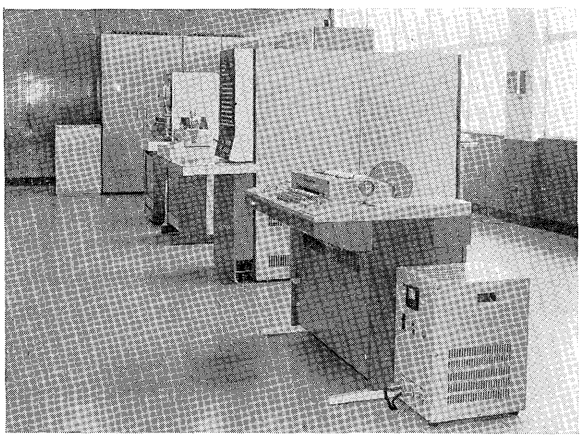


Fig. 7 Computer room

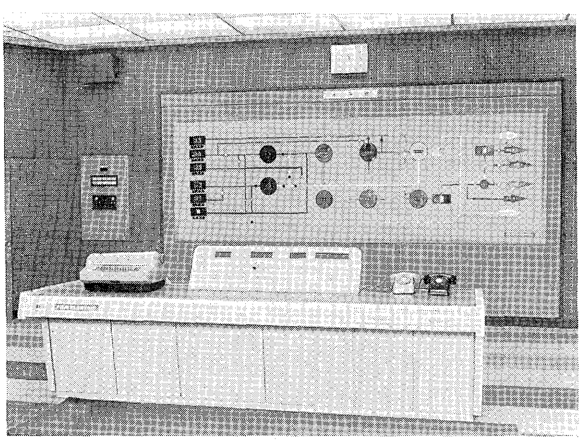


Fig. 8 Central control room

Analog output	4 points
Digital input	512 points
Digital output (hold type)	128 points
Digital output (instant type)	128 points
Typewriter output	2 points
Clock	1 point)
Timer	4 points

Fig. 7 shows the computer room. From the front of the photo, the first unit is the input/output unit, followed by the central processing unit, the high speed paper tape read unit, the high speed paper tape puncher the relay panel and at the back of the room, the real time controller. *Fig. 8* shows the graphic panel and the operation desk in the central control room.

IV. COMPUTER CONTROL OF THE PURIFICATION PROCESS

The task of the purification works is to guarantee that varying water requirements are normally fulfilled. In order to fulfil these requirements and distribute the water rationally, it is essential to know the pattern of change in the requirements beforehand. It is possible then to have a water intake corresponding to requirements by predicting requirement changes and also the most appropriate reservoir and pump operating methods can be decided.

The equipment processes in the purification works are shown in *Fig. 9* in respect to the water flow. The control system is aimed at complete control from intake to supply. The requirements for clear water are first predicted, and on the basis of this prediction the amounts of water for supply to the required clear water reservoirs and the filter efficient flow are determined as shown in *Fig. 10.* If the filter effluent flow rate is known, it is possible to compute the required amount of industrial water

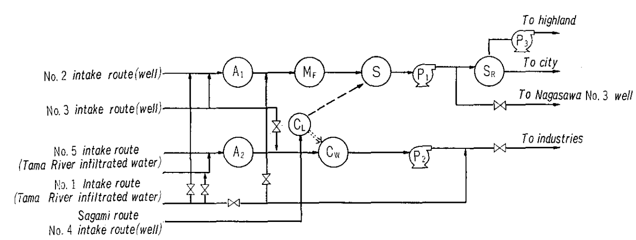


Fig. 9 Water flow diagram

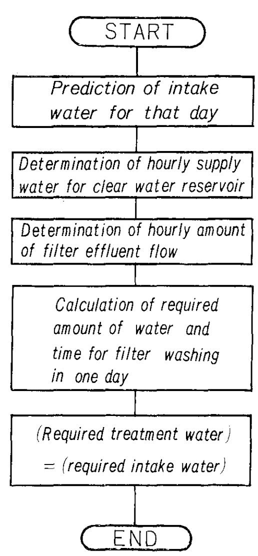


Fig. 10 Estimation of intake water quantity

and the hourly rate for purification per day. The amount of intake water can also be determined. Since differences between the requirements and predicted amounts appear becuase of direct changes in the water level of the clear water reservoir, the predicted amount is corrected in accordance with the water level of the clear water reservoir. In the same way, the filter effluent flow and the amount of intake are corrected for changes in the water level of the purification reservoir, and the normally required amount of water can be assured. In the case of industrial water, it was estimated beforehand that the changes in requirements per day would be about ±10% for this purification plant and the intake water is based on the distribution water curve determined previously. However, as in the case with the clear water, corrections in respect to changes in the water level of the sedimentation basin are computed.

The control methods will be described below but since the water level control methods for the purification reservoir and the sedimenation basin are the same, and the methods for the clear water reservoir supply pump, the highland clear water pump and the industrial water supply pump are also the same, examples will be given only for water level control in the clear water reservoir and highland clear water pump control.

1. Prediction of amount of distribution water

Since the amount of distribution water varies in accordance with such complex factors as the climate, temperature, humidity, normal days and holidays, etc., accurate predictions are extremely difficult. There are several methods for predicting the amount of distribution water: for example, even when the prediction is made on the basis of pattern classifications according only to natural weather conditions, it is unavoidable that climatic specifications differ according to the person and weather conditions outside the patterns will arise. In this purification works, therefore, the amount of distribution water is estimated comparatively accurately by means of computers without the intervention of operating personnel, and reproted to the Kawasaki Water Department.

By this method, there is a close relation between the integrated amount of distribution water from 0 hours to some specified time and the daily amount of distribution water. Since this correlation is very strong, a single regression module of the primary integer type is mode by a regression analysis of both. In this way, the amount of distribution water per day is estimated. Assuming thar the amount of clear water required per day is Q, the integrated amount of distribution water from zero hours to some specified time point is $q\ (t)$; then the equation is:

$$Q=aq(t)+b \quad \cdots\cdots (1)$$

which is of the first order. The coefficients a and b are calculated from the previous numbers and the integrated monthly distribution water data of Q and $q\ (t)$ by using the method of least squares. If the integrated distribution water amount $q\ (t)$ up to some optional point of time that day is substituted, the total amount of distribution water for one day, Q, can be obtained.

When predicting the amount of distribution water for one day, and only the amount of water needed that day is known, it is necessary to predict the amount of distribution water every hour in order to determine the pump operation method and the method of using the reservoirs. For this prediction as in the case of predicting the amount of distribution water for one day, there is a strong corelation between the amount of distribution water at any time during the day and the total amount of distribution water for the whole day. Therefore, the distribution water coefficient between the two is defined as in the following equation.

$$d=\frac{q}{Q} \quad \cdots\cdots (2)$$

where: d: coefficient of distribution water at any time

q: amount of distribution water at that time

Q: amount of distribution water for one day

From the above, the amount of distribution water at any optional time can be obtained from the following equation.

$$\hat{q}=d\hat{Q} \quad \cdots\cdots (3)$$

where: $\hat{Q}$: predicted amount of distribution water for one day

d: distribution water coefficient for any optional time

$\hat{q}$: predicted amount of distribution water at that optional time

The ratio between the hourly predicted amount of distribution water for the Kawasaki City water system obtained by this method of estimation and

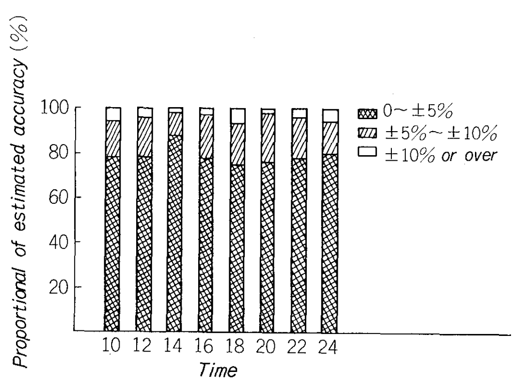


Fig. 11 Estimation accuracy of water supply a day

the actual hourly amount of distribution water was calculated and the accuracy of the prediction can be seen in *Fig. 11.*

When preforming actual on-line control, the predictions are made in units of hours and the following steps are taken because of the need to consider seasonal changes and extensions in demand.

(1) The coefficients a and b of equation (1) are changed daily on the basis of data for the past two months.

(2) The coefficients of distribution water are calculated for the preceeding two months by means of ratio of the amount of distribution water every hour to the total amount for the day, and the average value is taken as the initial value. It is changed daily in accordance with the following equation

$$d_{(i+1)}t = \frac{q_i t}{Q_i}\alpha + (1-\alpha)d_i t \quad \cdots\cdots\cdots\cdots (4)$$

where : Q_i : actual total amount of distribution water for i day

q_i, t : actual amount of distribution water at $(t \sim (t+1))$ hour of i day

$d_{(i+1)}, t$: coefficient of distribution water at $(t \sim (t+1))$ hour of $(i+1)$ day

$d_i\, t$: coefficient of distribution water at $(t \sim (t+1))$ hour of i day

a : values from 0 to 1, and $(1-a) > a$ is used to show degree of seasonal and trend changes

In other words, at the time when day i is completed, a, b, and $d_{(i+1)}, t$ are calculated on the basis of the latest data and the amounts of distribution water for the day and for each hour are predicted by using the actual integrated amount of distribution water from 0 hours to 9 a. m. at 9 a. m. Since this predicted value becomes the basis for the amount of distribution water and the method of operating the purification works, it is corrected twice every hour in accordance with the water level of the clear water reservoir.

2. Control of the distributtion process

1) Water level control of clear water reservoir

The clear water reservoirs of the Ikuta Water Purification Works are as shown in *Fig. 12.* The water supplied from the clear water reservoirs is supplied by reservoirs No. 1, 2 and 3, and reservoir No. 4. However, the water in resevoirs No. 1, 2 and 3 does not remain there, since the pipe to reservoir No. 4 is tightened. The equipment position and the diameter of the piping between the Nos. 1, 2 and 3 reservoirs and the No. 4 reservoir present a problem and the difference between the amount of water entering the clear water reservoir and that leaving the reservoir appears directly as a change in the water level of the No. 4 reservoir. Therefore, when corrections are made on the basis of the water level in reservoir No. 4, the pump must be started and stopped very often and when based on the water levels of reservoirs No. 1, 2 and 3, the changes in demand can not be accurately decided and therefore, the average value of the two reservoirs is controlled as the water level of the clear water reservoir. Upper and lower limit values for control are established as the upper and lower limit alarm values and when the water level of the clear water reservoir is set beforehand, the previously set amount of water supplied to the clear water reservoir does not change in this dead zone and the clear water reservoir water level is corrected according to the following equation when this dead zone is exceeded.

$$Q_i = Q_{si} - \Delta H \cdot E \quad \cdots\cdots\cdots\cdots\cdots\cdots (5)$$

where : Q_{si} : Actual total of distribution water

ΔH : (Upper/lower limit—actual level)

E : Surface area of clear water reservoir

Q_t : Corrected value of water supplied to clear water reservoir

In the same way, the amounts of filter effluent and intake water are corrected by the water level of of the purification reservoir and the amount of industrial intake water by the water level of the sedimentation basin.

2) Highland clear water pump control

Matching of the clear water pumps which is required in order to maintain the necessary pressure in the main pipes in respect to the various amounts of distribution water is preformed by using the Q–P curves. Referring to this, the number of operating

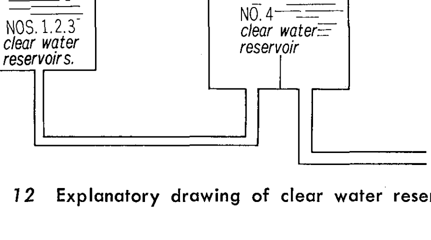
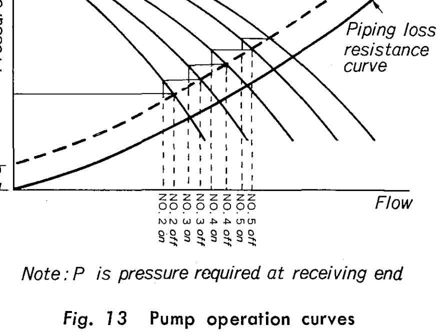


Fig. 12 **Explanatory drawing of clear water reservoir**



Note: P is pressure required at receiving end

Fig. 13 **Pump operation curves**

clear water pumps is selected and controlled. As can be seen in *Fig. 13*, there are hysteresis characteristics in respect to increases or decreases in the amount of flow when selecting the matching groups and changes in the unnecessary number of pumps for operation have been eliminated. When each pump is selected, the time is monitored so that a particular pump is not operated or stopped for too long a period, Pumps operated for more than 48 hours are stopped and operation is switched to a pump with the longest hours of operation remaining. When there is a fault in the flowmeter, the pressure is controlled to maintain safety.

3. Control of filtration process

The predicted amount of distribution water obtained from calculations of predicted amounts of distribution water serves as the standard amount of of filter effluent flow and the aim of filter effluent flow control is to control the filter so that this amount is maintained. The characteristics of the amount of effluent flow of the filter are not the same for each reservoir and it is difficult to perform control for each reservoir from the viewpoint of equipment. Therefore, of the systems used for control of total filter effluent such as constant flow filtration, decrease flow filtration, filtration number control and effluent valve positition control, this system employs decrease flow filtration as the main control with filtration number control and effluent valve position control used in conjunction. In this system, the number of reservoirs operoting and the valve positions required for input of the water are calculated and the amount of raw water input, i. e. the total filter effluent flow, is controlled.

Comparison of the amount of raw water input and the current amount of filter effluent flow is performed every 20 minutes and when the differences exceed the previously decided permissible limits, the positions of the effluent valves are controlled first, and if the valve positions can not be controlled, control is shifted to filtration number control.

The relation between the number of operating filtration reservoirs and the total filter effluent is controlled as shown in *Fig. 14*. One reservoir is added or subtracted for every change of 10,000 m^3

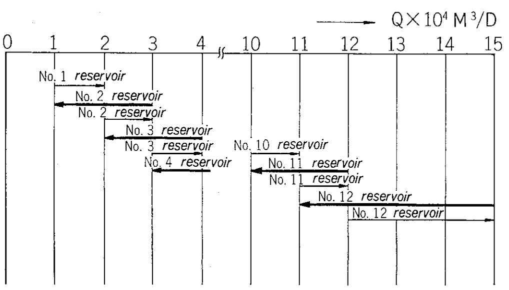


Fig. 14 Relations between filter total effluent flow and number of filtration

in total amount of filter effluent. When the source water input is increased, one more reservoir is operated for every 10,000 m^3 and when the raw water input is decreased, one reservoir is stoppings of the reservoirs are avoided and the valve positions are calculated simultaneously. Control is performed so that water level changes are supressed under transient conditions until the raw water input and total filter effluent in respect to adjustments in the number of filtrations are equal.

Purification conditions include filter resistance, filtration time, amount of filter effluent and degree of filtered water tubidity. However, under the two conditions of (1) filtration time: 48 hours and (2) amount of filter effluent: 26,000 m^3, a purification instruction is given when these two conditions are achieved. When this purification instruction is given when these two conditions are achieved. When this purification instruction is given, opening and closing of the source water and pure water valves is preformed automatically in sequence. When purification is completed, a completion signal is received and a stop instruction is given.

The following measures are taken by the computer for control of the filtration process:

(1) Monitoring of filter conditions
(2) Monitoring of filter time
(3) Calculation of total filter effluent

4. Control of sedimentation process

The items which must be controlled in the sedimentation process include the amount of water treated, the injection of chemicals, and the removal of dirt. However, sequence control of the accelerator will be stressed here.

The four accelerators are constructed as in *Fig.* The coagulant is mixed in accordance with the amount of raw water and flock is formed. This mixture is stirred and any impurities in the raw water are removed as sediment. Since the dirt accumulates in the accelerator which combines the functions of a flocculation basin and a sedimentation basin, it must be removed periodically. The concentrator valve and the center drain valve are regulated so as to maintain optimum slurry density conditions in the accelerator tank in order to make flock formation more effective.

1) Concentrator gate

The number of concentrator gates, is calculated

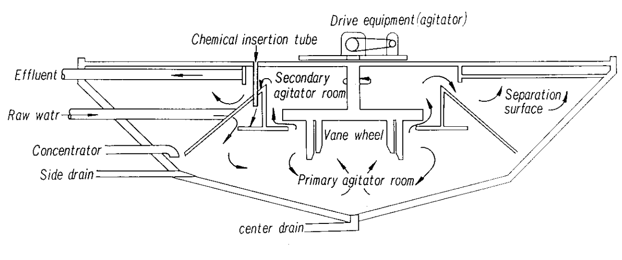


Fig. 15 Accelerator

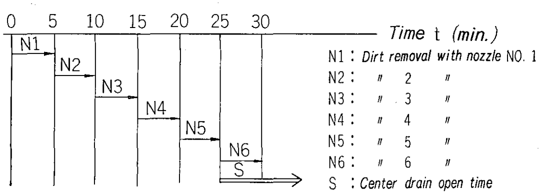


Fig. 16 Accelerator nozzle operation process

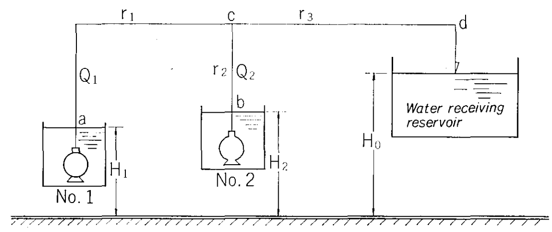


Fig. 17 Explanatory drawing of intake water well

every hour in respect to the raw water turbidity so that the slurry density in tne slurry pool can be kept constant by regulating the number of concentrator gates. When there is a change in the number of gates, a report is made on the typewriter of the accelerator number and the number of gates.

2) Concentrator valve control

Since the slurry density is held constant be the concentrator gates, excess slurry must be removed periodically when it accumulates. Therefore, the amount accumulated and the amount removed as the removal time are calculated aud the removal removed as well as the removal time are calculated and the removal instruction is given periodically. The amount removed and the time required can be obtained from equation (6)

Amount removed

$$=\frac{\text{raw water input}\times(\text{raw water turbidity}-\text{treated water turbidity})}{\text{percentage removed}} \cdots\cdots\cdots\cdots (6)$$

Time of one removal

$$=\text{amount removed}\times\frac{1}{\text{removal period}}\times\frac{1}{K_\beta}$$

$$K_\beta=K\times a$$

where : K_β : amount removed for number of gates used

K : number of gates

a : amount removed per gate

3) Center drain valve control

At a previously determined time, nozzle dirt removal is started by the nozzle dirt removal instruction and the dirt which has accumulated all over the bottom of the accelerator tanks is concentrated in the vicinity of the center drain during nozzle dirt removal. The nozzle operation process is as shown in *Fig. 16.* When the sixth nozzle dirt removal begins, the center drain valve is opened and the dirt which has accumulated in the vicinity of the drain is efficiently removed. The time which the center drain valve remains open is determined by the amount of dirt which has accumulated in the bottom of the tank and also by other requirements. This time is then set on the setting panel.

5. Control of the intake water process

As was described previously, the two main intake water sources for the Ikuta Water Purification Works are the Tama River and wells. However, since the pump for the Tama River water can not be remote controlled, the required intake water is insured by control of the pumps located in the wells. The method of calculation when the water intake is from the wells is obtained as follows. Considering the case shown in *Fig. 17* where the water is taken from two wells, the pump shaft power is shown by the following equation :

$$P=\frac{9.81\,QH}{E} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (7)$$

where : P : pump shaft power (kW)

Q : amount of water pumped up (l/s)

H : total head (m)

E : pump efficiency

The head loss from the No. 1 well to the intake reservois can be shown by the Hazen equation as follows :

$$H=Q_1^{1.85}\gamma_1+(Q_1+Q_2)^{1.85}\gamma_3+(H_0-H_1) \cdots\cdots\cdots (8)$$

where : $\gamma=10.665\times C^{-1.85}\times D^{-4.85}\times l$

C : rough speed coefficient

D : pipe diameter

l : pipe length

Q : flow

In the same way, the value for well No. 2 is given by the following equation :

$$H=Q_2^{1.85}\gamma_2+(Q_1+Q_2)^{1.85}\gamma_3+(H_0-H_1) \cdots\cdots\cdots\cdots (9)$$

In this case, equations (8) and (9) are simultaneous equations and if Q_1 and Q_2 are obtained, the amout of intake water can be calculated. When there are n wells, the concept is the same and n simultaneous equations can be formed. Since the equations are of the hypercomplex, high dimension type, they are solved by the Newton method.

In this intake water calculation method, there are major changes in the actual head due to adjustment of the intake water in accordance with seasonal changes and therefore, the water level of the wells is an important factor in the amount of the water intake. The major factor which controls the water level of the wells is the occurrance of a water flow gradient necessary for the water to flow from the water-bearing strata to the well. Therefore, a decrease in the water level is rapid at first and gradually becomes slower. The water level is stable when the water supply conditions are such that a water supply is easy to obtain.

This stable water level differs according to the natural water level, the amount of water pumped up, etc. Even for the same amount of pumped-up water, there are differences is period of plentiful water and periods of scarce water, and with so many factors, it is difficult to obtain the correct values; therefore, it is obtained by the following methods. The following two levels:

1) Water level at which water intake is levels:
1) Water level at which water intake is impossible
2) Decreased water pump starts are calculated for each well from past data and the operating level is obtained in accordance with current operating conditions. If the head is less than that of 1) above, that well for which water intake is impossible is not controlled.

The time is impossible as with the supply pumps so that a certain pump is not operated for too long a period.

6. Chemical treatment process

The injection of chemicals can be divided into two parts: one before treatment and one after treatment. Before treatment, the coagulation auxiliary agents (sulphate band, pack etc.) and chlorine ("before" chlorine) for sterilization are added. After treatment, chlorine ("after" chlorine) is added.

The injection is performed by the rotation speed control method. Stroke control is also performed indirectly.

The amount to be injected is calculated as shown in equation (10). The stroke position is compared with the value set beforehand and when it is found to be insufficient, a stroke position change instruction is given by the typewriter.

$$\text{Amount injected } q = F \times P \times S \qquad \cdots\cdots\cdots\cdots (10)$$

F: amount of raw water
S: stroke position
P: percentage of injection

Chlorine is injected after treatment but the proportional control method is used. At the clear water reservoir outlet, 0.8–1.0 ppm of effective chlorine remains and this residual chlorine is detected. On the basis of the amount of distribution water obtained from the distribution water prediction reservoir and the clear water reservoir is calculated. Control is performed so that the standard value at the clear water reservoir outlet is achieved. The "after" chlorine injection percentage is the injection percentage considering the lost portion of the chlorine.

7. Data logger

The logging typewriter prints out a total for each hour and also a daily total for 24 hours.

8. Data processing

Data is punched out every hour on paper tape under 91 items.

V. DATA TRANSMISSION

The aim of data transmission is the smooth and economical operation for the city as a whole of the purification works located throughout Kawasaki city. By means of this data transmission, measures can be taken when there is a sudden increase in the clear water in one of the works or when a fault occurs. It is also possible to use the water more economically and the problem of leaks can be solved. The data required for transmission include the possible amount of intake water, degree of tubidity of raw water, treatment capability, demand prediction, etc. Because of the large amount, the data are transmitted in separate texts in the manner shown below.

1) Transmission speed is 200 bits/sec.
2) Transmission is character series and bit parallel.
3) The code is the ISO code with an 8-unit even-number parity.
4) The data are composed of a message part and a data part.
5) The message part consists of 6 characters.
6) The data part consists of asign and 3 columns of decimal characters, a total of 4 characters.
7) Only the message part can be transmitted but the data part can not be transmitted alone.
8) When there is a data part, transmission is in the sequence: message part, data part.

Data are transmitted at least once a day in accordance with the above form. When ever there are abnormalities such as the fact that the required amount of water is impossible for intake, or a fault occurs, data are transmitted.

VI. CONCLUSION

The central control and monitoring system of the Ikuta Water Purification Works of the Kawasaki City Water Department has been outlined in this article. The operation of the requirement predictions are correct, a wider range of water system control is possible through data transmission. This computer control, completely achieves its primary goal through data transmission as the first step in the wide range control of water systems and also the complete automation of water purification works.

Later articles will provide an opportunity of report subsequent experience and future developments.