

INSTRUMENTATION OF CHEMICAL PLANT

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I. PREFACE

When speaking of automation in process industries, a large scale petroleum refining plant or chemical plant can be given as a typical example of industrial automation; in fact, it was first developed in this field and even at present its development is not yet complete. Instrumentation by TELEPERM and TELEPNEU have been showing good results: this paper will introduce some actual examples.

II. INSTRUMENTATION IN FERTILIZER INDUSTRY

1. Instrumentation of Urea Plant

In synthesis of urea there are various methods, a typical one being the gas separation circulation method (total circulation method) which uses natural gas as raw material. *Fig. 1* is a photograph of a plant using such a method. *Fig. 2* is a schematic drawing of the process. Urea plant instrumentation by this method has been introduced in Vol. 8, No. 5 (1962) of this Review. By referring to this article for details, the fundamental rules for planning instrumentation of a modern urea plant can be stated below:

(1) Centralized control system

Mutually related operations between the

various processing schedules can be carried out smoothly which raises the total production efficiency.

(2) Adoption of small-size instruments

Instruments in a centralized control system must necessarily be smaller in size. *Fig. 3* shows one part of instrument board in a central control room composed of TELEPERM and TELEPNEU.

(3) Transmission by unified signal

Measuring signal and control signal are all transmitted by TELEPERM unified signal (0~50 mA) or TELEPNEU unified signal (0.2~1.0 kg/cm²).

(4) Adoption of unit system meter

The demand for simplification of operation and for lessening spare parts has led to the adoption of instruments composed of units possessing independent functions. Apparatus by TELEPERM and TELEPNEU systems are composed of independent units; at the same time they have a mutually common unit between respective apparatus.

2. Instrumentation of High-degree Metamorphosis Fertilizer Factory

1) Outline of Process

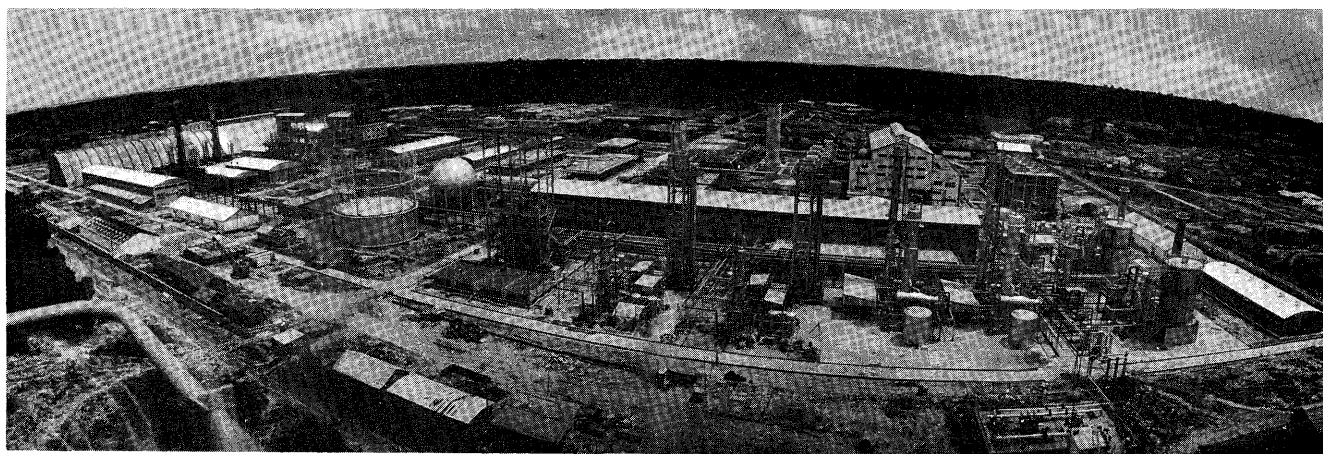


Fig. 1 General view of fertilizer factory

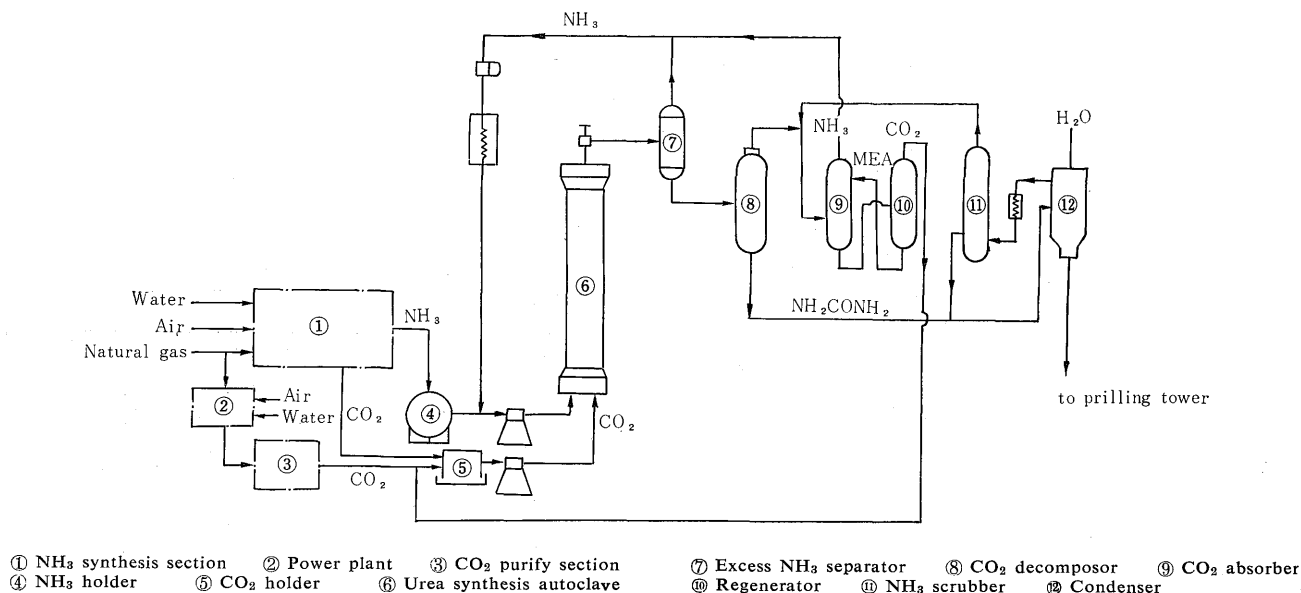


Fig. 2 Outline flow sheet of urea fertilizer factory

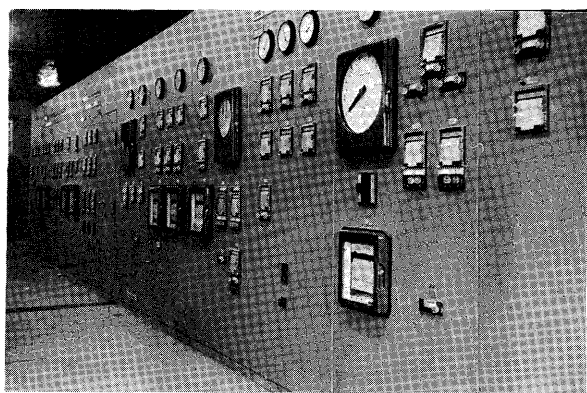


Fig. 3 Instrument panel in a central control room

One example of this process is shown in Fig. 4. Phosphoric acid solution manufacturing process: phosphate ore (fine powder) is decomposed by sulphuric acid; gypsum produced as a byproduct is filtered and separated, and phosphoric acid is obtained.

Decomposition of serpentine ore, ammonia making process: serpentine ore powder is mixed with phosphoric acid liquid and further decomposed by sulphuric acid. This liquid in a muddy state is treated with ammonia for first-step neutralizing; after adding potassium chloride is further treated for second-step neutralizing and nearneutralizing pH.

2) General of instrumentation

A high-degree metamorphosis fertilizer plant is small in scale compared to a urea plant; measuring control variables are comparatively fewer and so it is often seen that the instrument panels are distributed locally without providing a central control room. In the latest plants in which modern equipment has been installed, in order to raise operational efficiency of the whole process, including health control of

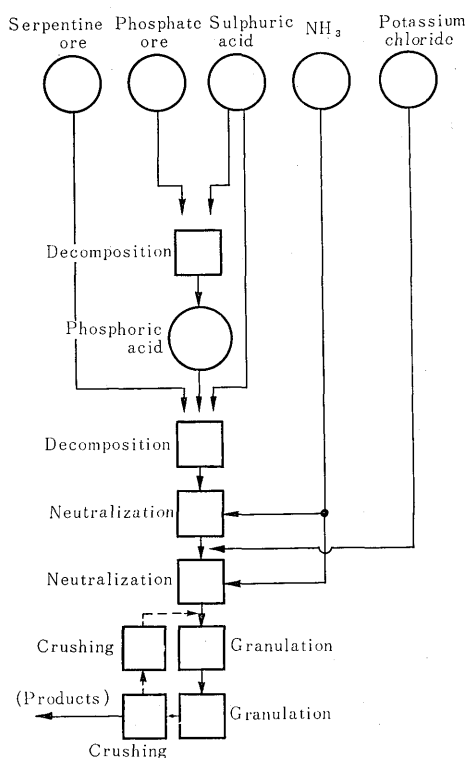


Fig. 4 Outline flow sheet of a high-degree metamorphosis fertilizer factory

workers, protection of panel instruments and attached processes, it has been customary to adopt a centralized control system.

Fig. 5 shows an example of such an instrument panel. Even in case of such a centralized control system, measuring control variables are comparatively few and consideration for diminishing size of instru-



Fig. 5 Instrument panel in a central control room

ment panel is not so important. Consequently, mainly from the standpoint of economy, the instruments in a subprocess are large size; from the standpoint of PR effect and from the standpoint of intuitive operation handling, instrument panels for main processes become quite graphic by using Q Series instruments. It is usual that transmission distance is no greater than the limits of the pneumatic system, so the purely pneumatic TELEPNEU instrumentation is very effective. Atmosphere gas at the actual spot is mainly NH_3 and can be mentioned as one of the processes with the worst conditions among chemical factories. Fig. 6 shows the mounted state of the pneumatic control valve; powder of semi-product in white can be seen adhering to piping. From this atmosphere it also follows that instrumentation with TELEPNEU as the main factor is selected.

On one hand, for an efficient ammonia making reaction, the NH_3 gas flow must be measured with compensated instruments pressure and temperature. Consequently, for NH_3 gas flow transmitter, TELE-

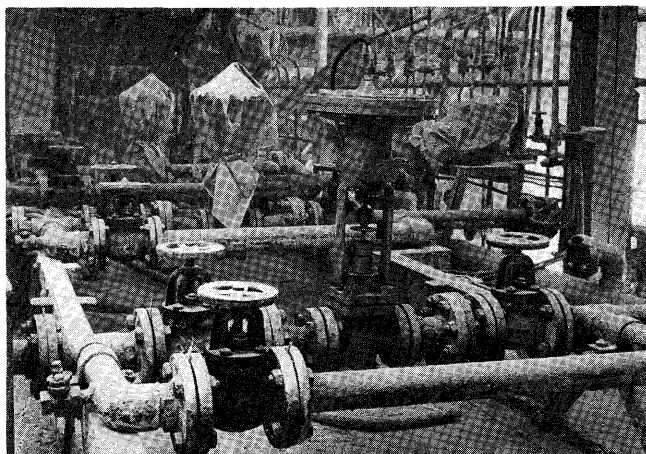


Fig. 6 Pneumatic control valves in NH_3 gas atmosphere

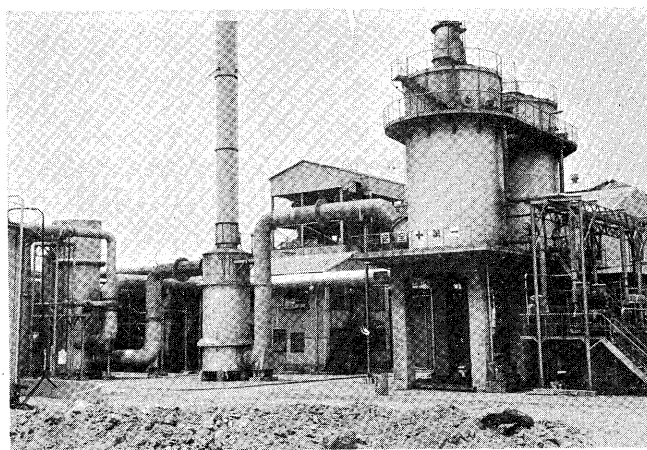


Fig. 7 Outer view of sulphuric acid plant

PERM flow transmitter with pressure and temperature compensation is used; its linear signal proportional to flow is extremely advantageous also for mixing ratio control.

Detailed descriptions of TELEPERM process instrumentation must be omitted due to secrecy; however, let it be understood that TELEPERM serves where exact calculation and ratio control are necessary. TELEPNEU and TELEPERM combined is giving the best solution technically and economically.

III. TELEPERM-TELEPNEU SYSTEM IN PETRO-CHEMICAL INDUSTRY

In the petro-chemical industry as in the fertilizer industry, TELEPNEU has become the core of instrumentation. In the initial stage, when plants were small and workers inexperienced, instrumentation by large-size pneumatic instruments was widely adopted. But recently, with plants becoming large in scale, as in fertilizer factories, the following instrumentation methods have been adopted:

- (1) Centralized control system
- (2) Smaller instruments
- (3) Unification of signals
- (4) Adopting of unit system instruments

The fundamental line of thinking has already been stated in II. The petro-chemical industry, because of the nature of fluids to be treated and atmospheric conditions, must consider the possibility of explosions: from this standpoint alone total instrumentation by TELEPNEU should be made.

Because the TELEPERM system's detecting is primarily done electrically, it is used in detecting all types of process variables, density measurements or those economical even when explosion-proof is considered, for example, temperature measurements and in detection in which varied types of calculations are necessary such as pressure and temperature compensation of a gaseous fluid flow. In infra-red gas analyzer, it has

succeeded in the measurement range of 0~500 ppm CO_2 and its delivered actual examples have attained about 120 sets. TELEPERM flow transmitter with pressure and temperature compensation is often utilized in ratio control or fixed set point control, which have wide setting range, from the merit that measured value after pressure and temperature compensation is sent by two transmission wires and transmitted signal is linear proportional to flow.

Q Series small sized instruments with their unified diminished dimensions combine with one another freely which make them adaptable in processes where instrumentation are after changed such as in batch processing and in pilot plants, etc.

IV. INSTRUMENTATION IN CONTACT SYSTEM SULPHURIC ACID PLANT

1. Outline of Contact System Sulphuric Acid Plant

In process drawing (Fig. 8) sulphur dioxide (SO_2) gas having a temperature of 300 to 500°C generated from roasting furnace is relieved of large-grained dust particles and impurities by dust Cottrell. Fine dust and impurities that are still not removed are washed off by the next washing tower and cooled down to 30 to 40°C through cooling tower. In the cooled gas a large quantity of mist is present, removed by first mist Cottrell, intermediate tower and second mist Cottrell. In the gas passed through mist Cottrell, 20 to 40 g/m³ moisture is contained; if this is passed on to the next blower heat exchanger, corrosion will be increased; so in order to reduce moisture to about 0.1 g/m³, it is dried by a drying tower. Gas that is dried is passed through a filter by a blower and sent to heat exchanger and converter. Gas sent into the converter produces catalytic reaction through catalysis and is oxidized into sulphur trioxide (SO_3). Temperature necessary for catalytic reaction is constantly maintained by the heat exchanger.

Gas coming out from the converter by way of the heat exchanger is cooled, but is still too high in temperature (200°C) for the absorption tower, so it is further passed through a cooler to bring the temperature down to 100°C. (Sulphuric acid concent-

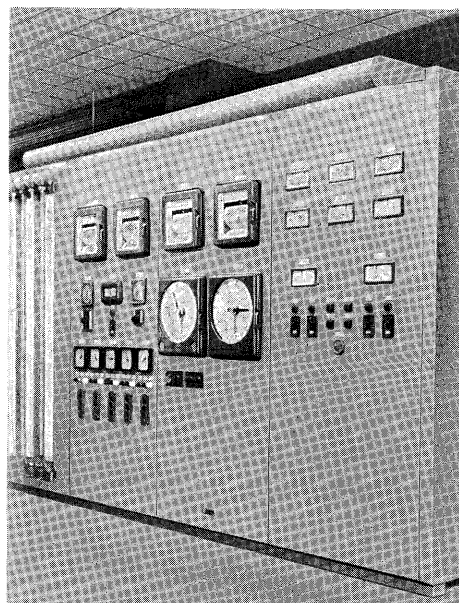


Fig. 9 Instruments panel of central control room

ration most suitable for sulphur trioxide absorption is that point where total vapour tension is minimum; and below this, concentration component pressure of water will be great, making sulphur trioxide form a mist with water and difficult to absorb.) Sulphur trioxide (SO_3) which has become about 100°C will be absorbed by 93.8% sulphuric acid through the absorption tower, and sulphuric acid of 98% concentration will be produced. In the case of two absorption towers, by circulating fuming sulphuric acid in first tower, it will be possible to produce fuming sulphuric acid.

2. Examples of Instrumentation of Contact System Sulphuric Acid Plant

1) Outline

Singular points in instrumentation of contact system sulphuric acid plants (including caustic soda plants) as compared with instrumentation of other processes are as follows:

(1) Transmission distance is comparatively long:

In sulphuric acid plants, distance between roasting furnace, cooling tower and desiccating tower is long; in caustic soda plants, brine treating process,

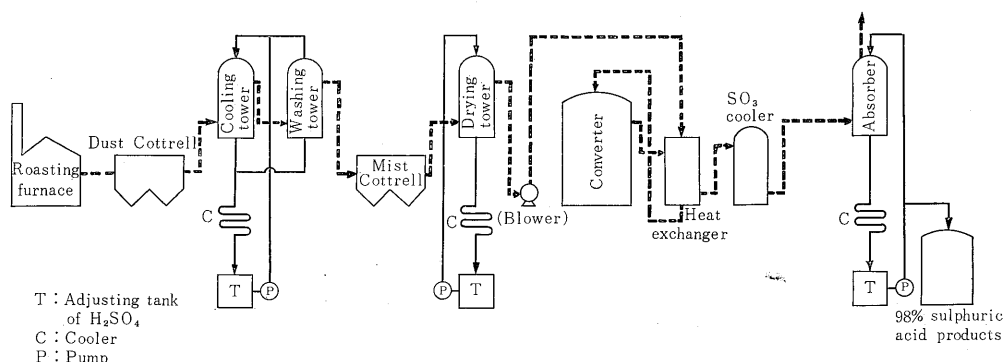


Fig. 8 Schematic diagram of control system sulphuric acid plant

electrolysis, concentrating, refining processes are dispersed in a wide range, and sometimes a transmission distance of about one km is necessary.

(2) Measurement control liquid and atmosphere gas are highly corrosive: sulphur dioxide (SO_2), sulphur trioxide (SO_3), sulphuric acid, etc., as well as chlorine (Cl_2) and hydrochloric acid (HCl) in caustic soda plants are so extremely corrosive that detective and final control units must be made of special materials. Special care must be given so that sulphur dioxide, sulphur trioxide, chlorine gas, etc., have no adverse effect on instruments, causing failures.

2) Examples of instrumentation

(1) Humidity regulating tunnel temperature measuring control: for detecting tunnel interior temperature and for regulating spray quantity of cooling water to be installed into tunnel, TELEPERM and TELEPNEU are being used. (See Fig. 10)

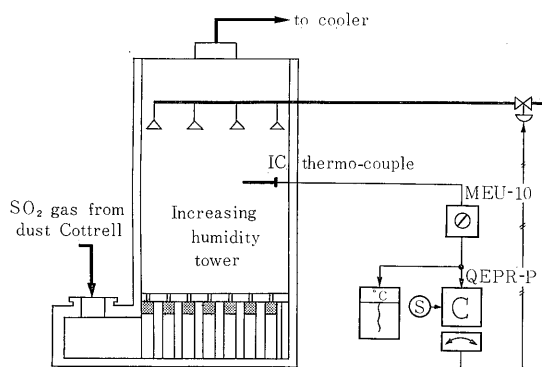


Fig. 10 Instrumentation diagram of temperature

Tunnel interior temperature is detected with an iron-constantan thermo-couple flange mounted from point of air tightness; by TELEPERM current converter (model MEU-10) is converted to DC 0~50 mA and transmitted to indicating recorder (model QES-110P), electric pneumatic controller (model QEPR) and manual selector (model QPV-11). The reason for using electric pneumatic type in tem-

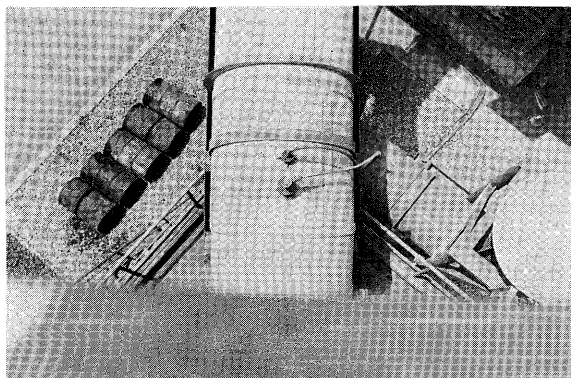


Fig. 11 Thermocouple at site

perature controller is for eliminating lag due to transmission distance from measuring point (thermometer) to centralized control room (instrument panel) and at the same time making good use of the merits with which pneumatic type diaphragm control valve (having great action velocity) can be used as a final control element. Protection for the thermometer is ordinary lead-covered steel tubing; the terminal boxes are hard vinyl chloride.

(2) Sulphur dioxide gas (SO_2) flow measurement: this control equipment is for finding total flow of material gas and also for maintaining constant flow most suitable for maximum operational efficiency, using head producer at detective element and TELEPERM differential pressure transmitter (model MMF) for differential pressure transducer: this is transduced into DC 0~50 mA current signals which are transmitted to unit system indicating recorder (model QES-110P), electric-pneumatic controller (model QEPR), manual selector (model QPV-11) and 5-digit integrator (model QDZ). Piping diameter of final control element is large, so butterfly valve is used. (see Fig. 12)

(3) Absorption tower pump tank acid concentration measurement: this equipment is an important part in the final production process of sulphuric acid; it is the apparatus which maintains concentration of highly concentrated sulphuric acid produced from the absorption tower, thus making the product uniform. Induction type density transmitter is used at detective element, connected to TELEPERM-TELEPNEU instruments (see Fig. 13). DC voltage signal 0~10 mV of density transmitter is received by TELEPERM current converter (model MEU-10) and converted into unified signal 0~50 mA, is transmitted to indicating recorder (model QES-110P) according to unit system, electric pneumatic controller (model QEPR) and manipulator respectively.

(4) Sulphuric acid tank liquid level measuring for drying tower and absorption tower: sulphuric acid is highly corrosive, so such types as float and torque tube types which directly contact

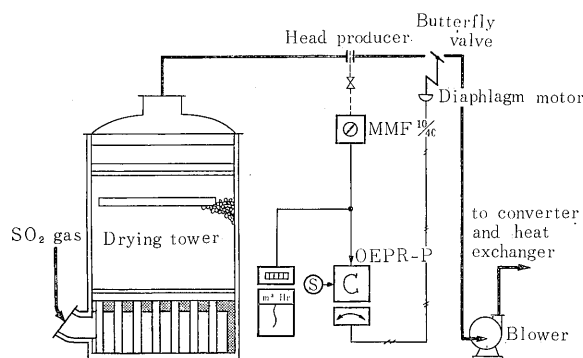


Fig. 12 Instrumentation diagram of SO_2 gas flow

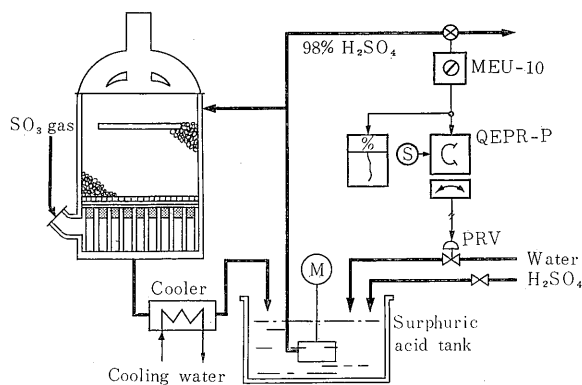


Fig. 13 Instrumentation diagram of sulphuric acid and density controlling device

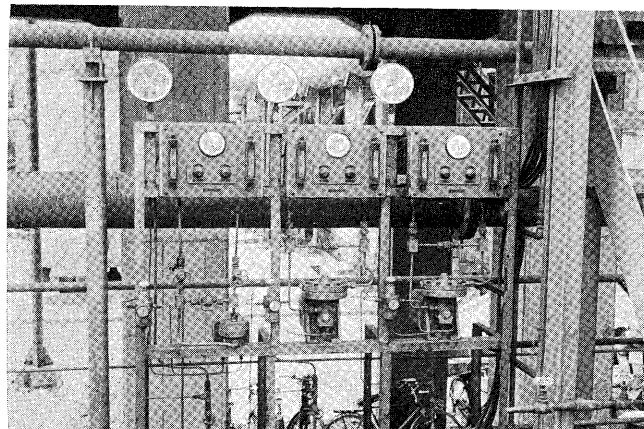


Fig. 14 TELEPNEU air purge level transmitter at site

liquid cannot be used. The measured object container is also quite small, making mounting difficult or construction impossible; for such reasons, bubble type liquid level transmitter has been often used. In the bubble type liquid level transmitter, only the purge pipe inserted inside the container contacts the liquid, so corrosion is limited to the purge pipe only; changing this when it becomes corroded does not affect measurements in any way. TELEPNEU transducer (type PUF) changes the back pressure of the purge pipe to pneumatic signal of $0.2 \sim 1.0 \text{ kg/cm}^2$ and transmits it to TELEPNEU screen type indicator (model QPAB-V.)

V. INSTRUMENTATION OF MERCURY ELECTROLYSIS METHOD CAUSTIC SODA PLANT

1. Outline of process in mercury electrolysis method caustic soda plant

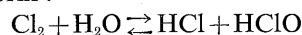
Manufacturing of caustic soda can be roughly divid-

ed into brine treatment, electrolysis and concentration. Fig. 15 shows systematic diagram of electrolytic method.

1) Brine processing

Raw material salt is thrown into the feeding hopper by means of a conveyor; after being electrolysed, it is mixed with dilute brine; the brine is then saturated. Decomposition rate of brine electrolysis is $10 \sim 20\%$; dilute brine drawn off of the decomposition tank is returned to the saturated solution tank, and by the above stated raw salt feeding, is again saturated.

This liquid drawn off is natrium chloride of $240 \sim 270\%$ saturation, but depending upon solution, will become concentration of about 300 g/l or thereabouts. Dilute brine drawn off contains chlorine in this form:



which corrodes equipment and emits chlorine gas in solution neutralization becoming a loss. Also ClO

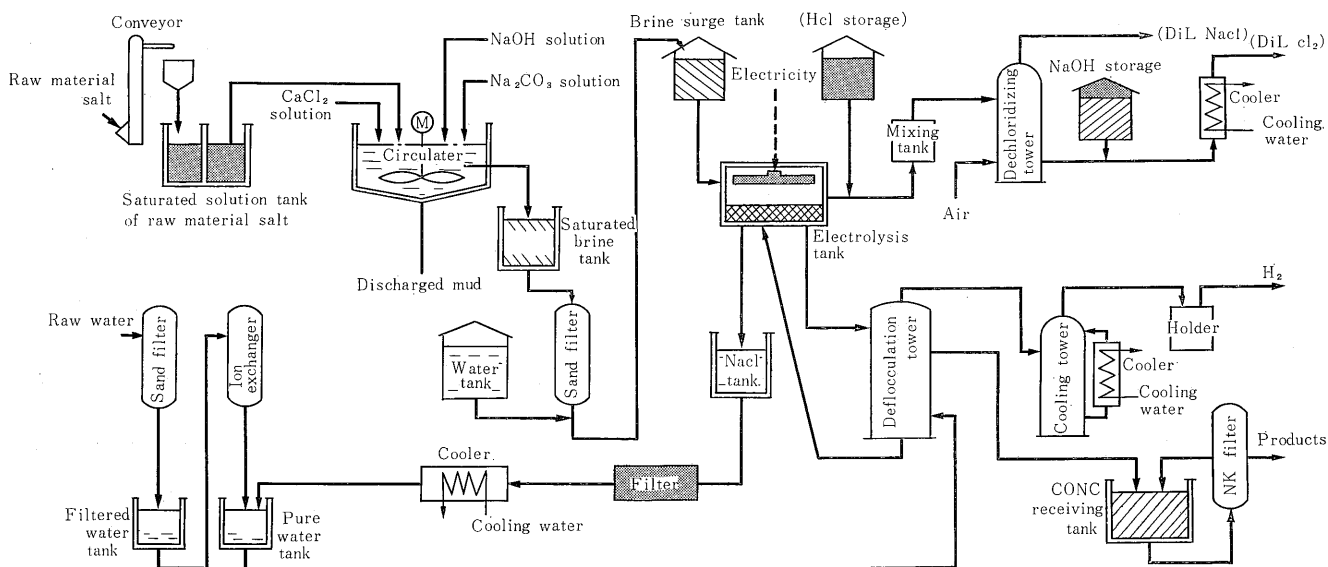


Fig. 15 Schematic diagram of caustic soda process

ions, slowing down sedimentation velocity in removal of impurities such as calcium magnesium, etc., have harm such as reducing current efficiency through their discharge, so de-chloridizing process is carried out by the de-chloridizing tower. Saturated salt water is then shifted to the process for removal of impurities. Kinds of impurities found in raw salt and their allowable content are shown in *Table 1*:

Table 1 List of impurities and allowable limit

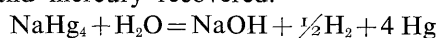
Impurities	Allowable limit	Impurities	Allowable limit
Mg	12 mg/l	Ti	900 mg/l
Ca	200 "	SiO ₂	30 "
Fe	0.3 "	Cr	0.03 "
Fe(+Mg)	0.03 "	V	0.04 "
Al	900 "	Mn	60 "

Brine from which impurities have been removed through above stated impurity removal process, because it is alkaline when refining, is neutralized by hydrochloric acid, and making it to about pH 6-3 or thereabouts, is sent into head tank.

2) Electrolysis process

Reaction in mercury method electrolysis with mercury as cathode and graphite as anode is shown by the following: $\text{NaCl (water solution)} \rightarrow \text{Na (amalgam)} + \frac{1}{2}\text{Cl}_2 \text{ (gas)}$.

Electrolysis equipment is composed of electrolysis tank and mercury deflocculation tank. The former, through the reaction shown by $\text{Na}_2\text{CO}_3 + \text{Ca(OH)}_2 = 2\text{NaOH} + \text{CaCO}_3$, sends sodium obtained by analysis (with mercury as cathode) into the latter as amalgam. The latter makes amalgam and water react, turning this into caustic soda and hydrogen, and taking out mercury, returns it to the former. Brine which will be repeatedly used is made at decomposition rate 10~20%, and is discharged from tank in parallel flow with mercury. In the deflocculation tank pure water is poured in, and by the following reaction, caustic soda and hydrogen are taken out and mercury recovered.



Temperature of electrolysis tank is 60~80°C and that of the mercury deflocculation tank 80~100°C. Composition of chlorine gas ordinarily is Cl₂: 98.1%, CO₂: 1.0%, H₂: 0.6, N₂: 0.2%, O₂: 0.1%. If hydrogen gas in relation with chlorine gas becomes above 5%, there is danger of an explosion: it should be maintained below 1%.

3) Concentration Process

Caustic soda drawn off from the mercury deflocculation tank will be a product in itself, but because its concentration is 45~50%, it is necessary to boil it down into a solid state for bag packaging.

2. Instrumentation example of mercury method caustic soda plant

1) Outline

Points that are peculiar in instrumentation of mercury electrolysis method caustic soda plant compared with other general process instrumentation will be enumerated below.

(1) Explosive nature of atmosphere gas: as has been explained in the process outline, an unfavorable ratio between H₂ and Cl₂ will cause an explosion; hydrogen itself 4~75% (in air) lies within the limits of explosion also, so extreme care in handling should be exercised.

(2) Application of feedforward-control: in high efficiency operation of mercury electrolysis caustic soda plant, feed forward-control according to *A·N* value is being applied.

2) Relation between electrolysis produced NaOH and other controlled variables

For safe and high efficiency operation of electrolysis method caustic soda factory, NaOH quantity produced by electrolysis, refined saturated salt water fed to electrolysis tank, consequently quantity of raw material salt fed in brine regulating process and mercury deflocculation water fed to mercury tank must have a constant relation to each other. Sodium (Na) that flows out from electrolysis tank has become mercury amalgam and also because it contains not yet decomposed brine in considerable quantity, it is not possible to measure Na quantity in a direct way.

(1) Electrolysis produced NaOH quantity and *A·N* value: electrolysis tank is connected electrically in series and with respect to liquid in parallel; if its electrolysis current is taken as *A*, and number of operated electrolysis tank as *N*, between produced caustic soda quantity (*Q·Na*) the following relationship will be formed:

$$Q_{Na} = \frac{60 A \cdot \eta \cdot e \cdot N}{96,500} = 2.36 \times 10^{-3} A \cdot N \quad \dots\dots(1)$$

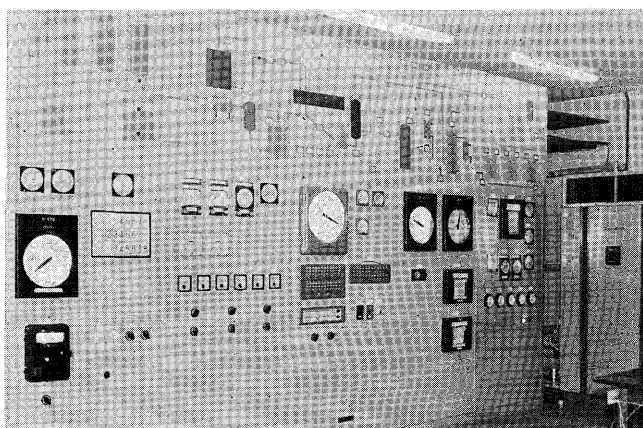


Fig. 16 Instrument panel of central control room

where Q_{Na} is quantity of produced caustic soda (kg/min)

A is electrolysis current (kA)

η is electrolysis efficiency (= .095)

e is quantity per NaOH 1 gram (=40)

consequently, by measuring $A \cdot N$ value, produced NaOH quantity can be indirectly measured.

(2) Electrolysis produced NaOH quantity and mercury deflocculation water quantity: water quantity Qw poured into tank is

$$Qw = Qw_1 + Qw_2 \quad \dots\dots\dots(2)$$

where Qw is water quantity (l/min)

Qw_1 is quantity required for decomposing amalgam (l/min)

Qw_2 is quantity required to dilute to constant concentration (l/min)

On one hand, between Qw_1 , Qw_2 and Q_{Na} , the following relation exists:

$$Qw_1 = 0.455 Q_{Na} \quad \dots\dots\dots(3)$$

$$Qw_2 = Q_{Na} \left(\frac{100}{a} - 1 \right) \quad \dots\dots\dots(4)$$

where a : NaOH concentration (%) for purpose of control

consequently Qw becomes

$$Qw = Qw_1 + Qw_2 = Q_{Na} \left(\frac{100}{a} - 0.545 \right) \quad \dots\dots\dots(5)$$

and from formulas (1) and (5),

$$Qw = 236 \times 10^2 \left(\frac{100}{a} - 0.545 \right) A \cdot N \quad \dots\dots\dots(6)$$

that is, water quantity to be poured in will be determined by $A \cdot N$ value.

3) Concrete examples of instrumentation

(1) Brine regulating process:

a) This detects saturated salt water quantity poured into circulator passing through heater from saturated dissolving tank and issues signal for ratio control of caustic soda thrown into circulator; is a desirable detective system from the standpoint of corrosion, etc., of electromagnetic flow meter, but here, with regard to upkeep expense, a detective system by head producer is adopted. Fig. 17 is a schematic drawing of instrumentation with TELEPNEU as its core.

b) Ratio measurement control equipment of saturated salt water caustic soda solution: saturated salt water delivered quantity sent into circulator and poured-in caustic soda quantity are ratio controlled. Purpose of ratio control is for making pH value of circulator outlet brine have constant value and system setting ratio set value by cascade signal from pH regulator is adopted. Fig. 18 shows an example of combined instrumentation of TELEPERM and TELEPNEU.

(2) Instrumentation of electrolysis process

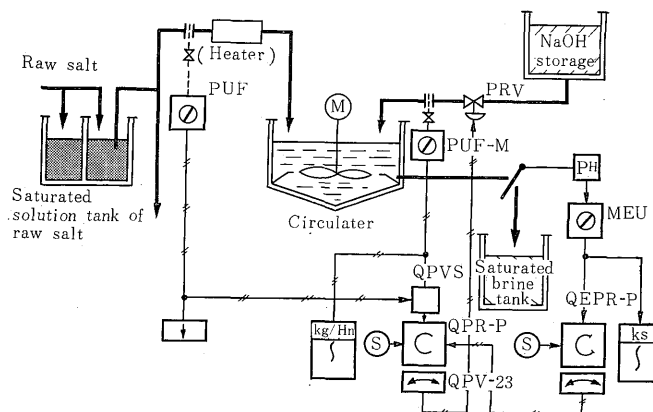


Fig. 17 Instrumentation diagram of pH and NaCl flow

a) Instrumentation of electrolysis tank feed salt water measurement control: measurement control of electrolysis tank feed salt water is the main control equipment of this process, and on this account, using recording controller with integrator connection in cascade is made with $A \cdot N$ signal value as feed quantity set value (see Fig. 18). Component apparatus are TELEPERM differential pressure transducer indicating recorder (model QES-110 P), integrator (model QDZ), electric pneumatic controller (model QEPR-P) and manipulator (model QPU-22).

b) Mercury deflocculation tower outlet caustic soda concentration measurement control equipment: concentration of caustic soda which will be the product is shown by mercury deflocculation tower supplied water and caustic soda concentration is detected by induction type concentration transmitter (see Fig. 20). Transmitter is covered with hard vinyl chloride in liquid contacting parts and consideration taken that it will withstand corrosion of caustic soda and with TELEPERM current transducer (model MEU-10) which transduces DC voltage signal (0-10mV) to unified current signal transduced to DC 0-50 mA and is transmitted respectively

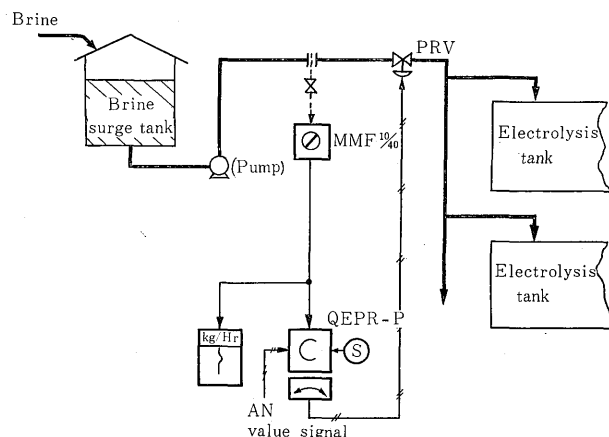


Fig. 18 NaCl flow recording control device

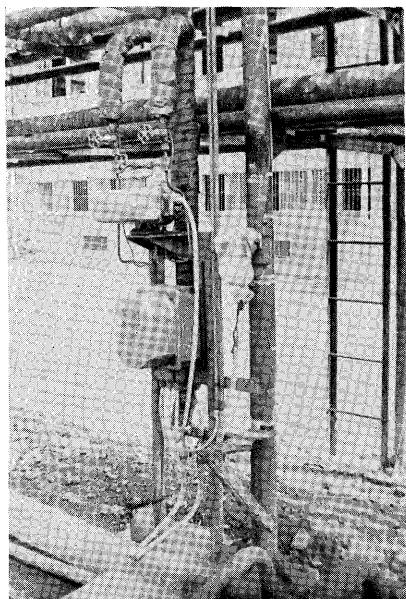


Fig. 19 TELEPERM flow transmitter

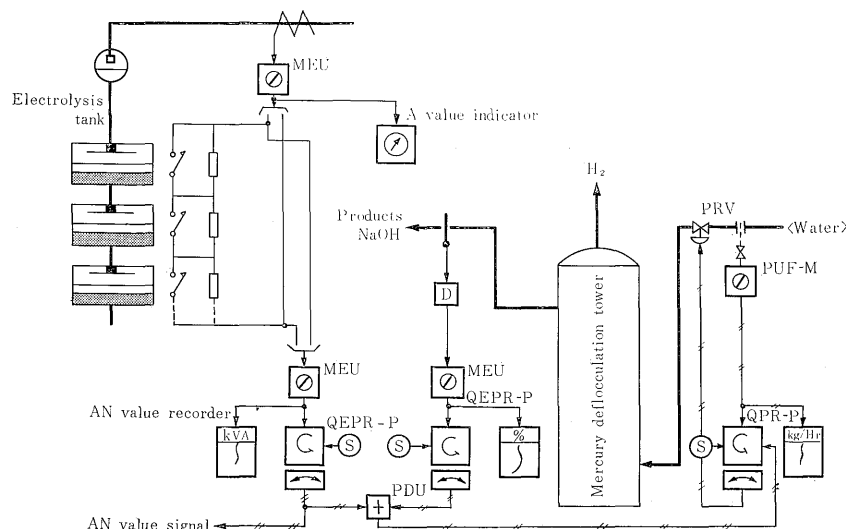


Fig. 20 Instrumentation diagram of water flow by $A \cdot N$ signal and caustic soda density

to indicating recorder (model QES-110 P), electric-pneumatic controller (model QEPR-P) manipulator (model QPV-11). Controller output $0.2 \sim 1.0 \text{ kg/cm}^2$ by pneumatic computing relay (model PDU) is added with $A \cdot N$ signal value and will be set input of feed mercury deflocculation water control. Computation in pneumatic computing relay (model PDU) is determined by formulas (2), (3) and (4). $A \cdot N$ signal transducer transmits only pneumatic pressure proportional to $A \cdot N$ value but density controller carries out PI action.

c) $A \cdot N$ value detecting equipment : for detecting current value A there are various methods and in Fig. 20, system for measuring AC current of rectifier primary side by ACCT is shown. For finding out number N of operating electrolysis tanks, it is most usual to do it by micro-switch attached to short circuiting lever on each tank. In Fig. 20, calculating and indicating method for product of electrolysis current value A with number of operating electrolysis tanks N . Also, cascade connection of mercury deflocculation tower outlet caustic soda concentration controller with mercury deflocculation flow controller and compensation method by $A \cdot N$ value are shown.

VI. CONCLUSION

In the above, instrumentation of chemical plants, using TELEPERM and TELEPNEU have been described. It is hoped that our readers have understood that TELEPNEU, which is essentially explosion-proof, is becoming the core of instrumentation, and that TELEPERM and TELEPNEU system (electric-pneumatic system) is the best solution both technically and economically in the instrumentation of large-scale plants by serving to facilitate operation and simplify maintenance of instruments.

With wide adoption of explosion-protected TELEPERM transmitters, instrumentation by TELEPERM system will also increase and it is considered that over-all advantages of TELEPERM-TELEPNEU system which makes good use of the merits of both electric and pneumatic system will be more and more fully displayed.

Reference

S. Yasuki and K. Nakamura: Electrical Power Equipment and Instrumentation Equipment for the Urea Fertilizer Factory, East Pakistan, Fuji Denki Review, Vol. VIII, No. 5, 1962.