APPLICATION OF NETWORK ANALYSIS IN THE MODELLING OF A CHEMICAL INDUSTRIAL COMBINE

By

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In the field of general chemical technology, the role of process engineering is growing steadily. At the emergence of process engineering mainly the complex interrelations between separate technological units were studied. In this work, in addition to the analysis of the single operational units, an overall aspect of the complete technological process gained ground.

Bound up with the progress of process engineering, studies were carried out which sought a method for the presentation of the process-flow within chemical manufacture. In our Department it was Professor M. KORACH, who initiated studies in this field [1].

As known, there are some accepted presentation methods for some industrial chemical processes, part of them having been standardized. Some design and project engineering firms have adopted special methods within the frame of these standards.

Presentation methods thus developed were generally suitable to allow composition of different operational units calculated separately. However, practice revealed that a technological sequence thus constructed is liable to allow bottle-necks to appear which have to be removed by dispositions realized subsequently.

A further complication was caused by the fact that quite often a new plant could not start with the raw material foreseen at design, or that, due to changes partly in the raw materials, and partly in marketing conditions, deviations in the yields of finished products had to be accepted or provided for.

The rigidity of the mentioned technological flow sheets did not allow the previous study of changes like these.

Progress in the theory of flow sheets is necessary also because the progress in automation necessitated leading parameters to be recognized, and a flow sheet must faithfully mirror possibilities of automation as well.

Thus the technological presentation method based upon the graph theory introduced by Academician KORACH was of a great significance. Extensive work was done in this Department in this field, resulting in the construction of technological graphs for basic technological units.

These technological graphs are featured by single plots in the graphs representing allactors or reactors, while the connecting lines correspond to technological material streams. Technological graphs are likely to be a step towards the mathematical modelling of the technological production unit expressed in the graph form.

This problem was further complicated by the fact that recently the process engineering of an entire system of production units has become necessary instead of the process engineering of a single technological unit. Ever more often plant combines are erected of which not only the production units need to be process engineered within the frame of the combine but the combine as an entity must be subjected to process engineering study.

As the science of unit operations has developed within the framework of petroleum refinery practice, so progress in process engineering too is being urged by the demands of petroleum processing and petrochemicals industry.

In the petroleum processing industry the principle gains predominance according to which eight, ten, or even more technological units are sited and realized as one closely joined technological whole. This principle prevails in the case of refineries like that of CALTEX at Frankfurt a. M., that of ENI at Ingolstadt, and in designs made by the Lengiprogas Institute in the Soviet Union.

This design practice requires that the entire plant system should be handled as a single process engineering unit, the modelling of which raises several problems.

Attempts have been made in this Department to develop a network model of complex technological systems, based upon results in the field of graph-theory.

For an experimental model the plant system in erection at Százhalombatta for a 3 million tons capacity of the Duna Petroleum Co. was chosen.

As known, this refinery, with a 3 million tons atmospheric and vacuum distillation capacity, will produce fuels for internal combustion engines, some aromatic hydrocarbons, lubricating oil, paraffin, bitumen, fuel oils, and elementary sulphur.

The choice of this model seems to be reasonable, because this petroleum processing and petrochemical combine, when considered from the point of view of process engineering study, presents to the researcher problems the solution of which brings him closer to the solution of problems posed by other combines.

The classical flow sheet of the model combine is given in Fig. 1. This shows that the capacity of 3 million tons derives from two units, from a 1 million, and a 2 million tons vacuum distillation unit.

Pentane free light gasolines are brought into a reformer of 300 000 tons, the reformate output is processed in an aromatic extraction plant. From the aromatic extracts benzene, toluene, and mixture of xylenes are produced

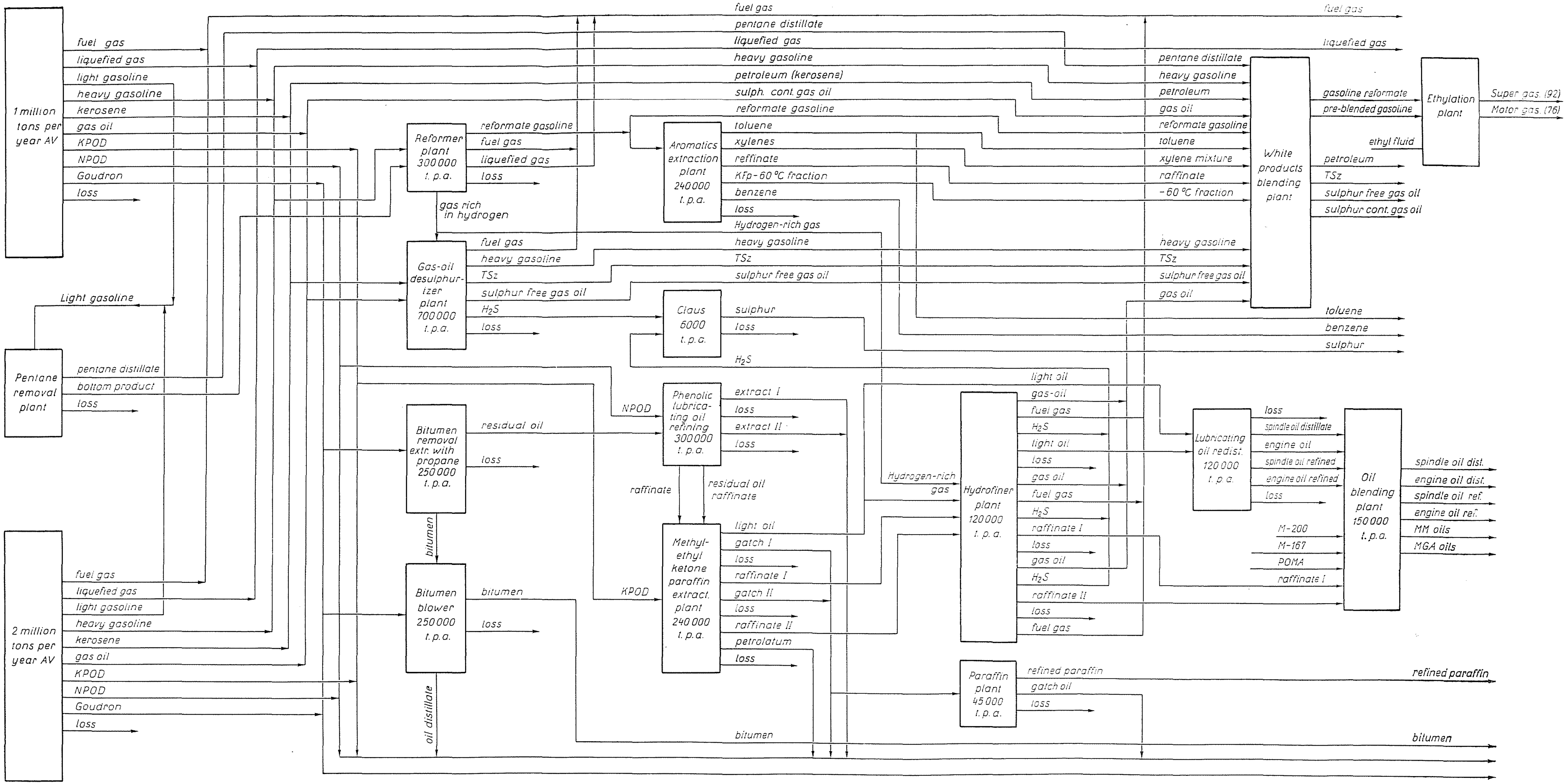
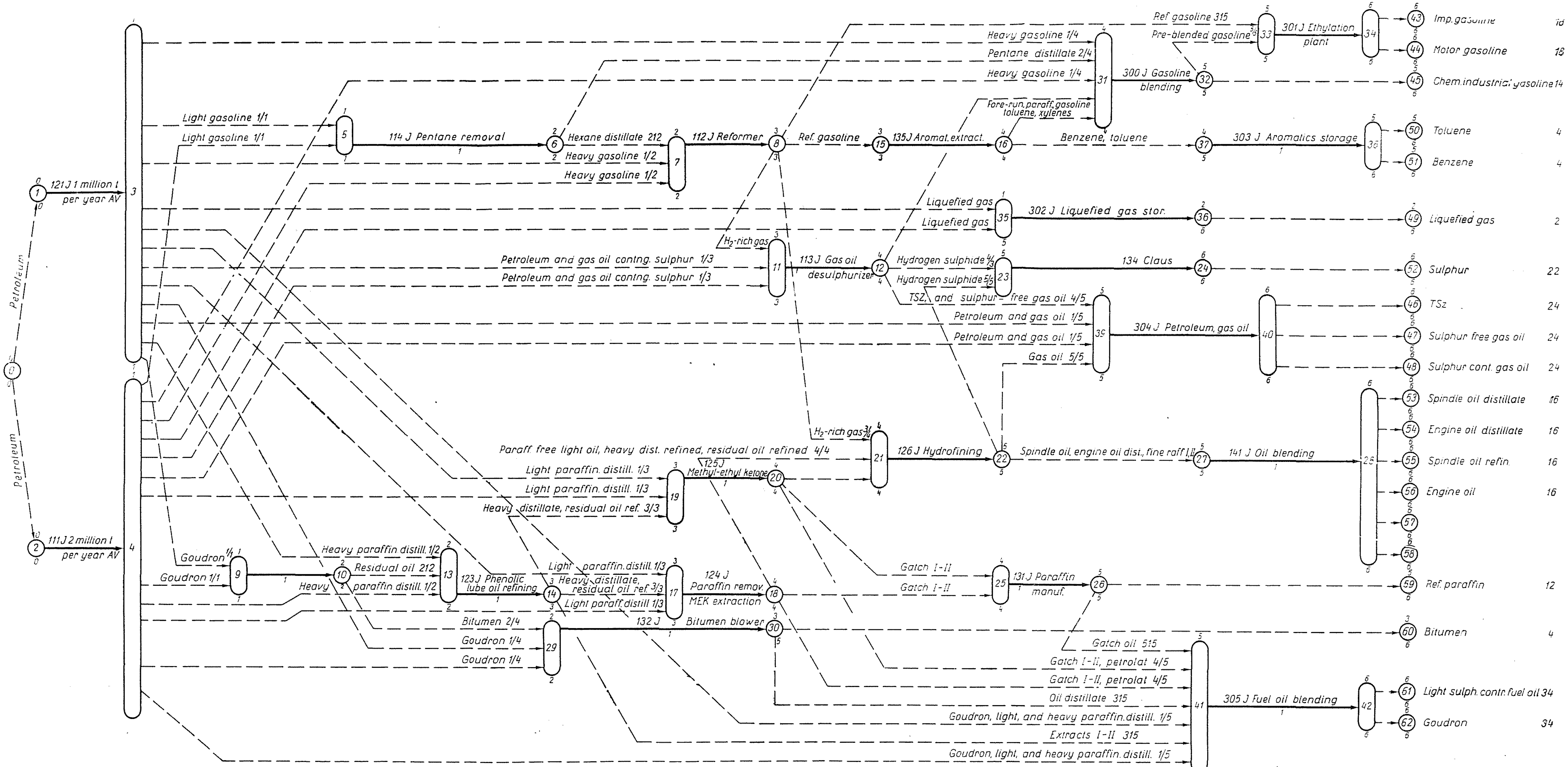

1 million tons per year AV
fuel gas
liquefied gas
light gasoline
heavy gasoline
kerosene
gas oil
KPOD
NPOD
Goudron
loss
pentane distillate
petroleum (kerosene)
sulph. cont. gas oil
reformate gasoline
Reformer plant 300 000 t. p. a.
gas rich in hydrogen
Aromatics extraction plant 240 000 t. p. a.
toluene
xylenes
raffinate
KFp-60 °C fraction
benzene
Hydrogen-rich gas
White products blending plant
xylene mixture
-60 °C fraction
gasoline reformate
pre-blended gasoline
ethyl fluid
Ethylation plant
Super gas. (92)
Motor gas. (76)
petroleum
TSz
sulphur free gas oil
sulphur cont. gas oil
Gas-oil desulphurizer plant 700 000 t. p. a.
H2S
Claus 6000 t. p. a.
sulphur
Light gasoline
Pentane removal plant
pentane distillate
bottom product
Bitumen removal extr. with propane 250 000 t. p. a.
residual oil
Phenolic lubricating oil refining 300 000 t. p. a.
extract I
extract II
raffinate
residual oil raffinate
bitumen
Bitumen blower 250 000 t. p. a.
oil distillate
Methyl-ethyl ketone paraffin extract. plant 240 000 t. p. a.
light oil
gatch I
raffinate I
gatch II
raffinate II
petrolatum
Hydrofiner plant 120 000 t. p. a.
Hydrogen-rich gas
Lubricating oil redist. 120 000 t. p. a.
spindle oil distillate
engine oil
spindle oil refined
engine oil refined
M-200
M-167
POMA
Oil blending plant 150 000 t. p. a.
spindle oil dist.
engine oil dist.
spindle oil ref.
engine oil ref.
MM oils
MGA oils
Paraffin plant 45 000 t. p. a.
refined paraffin
gatch oil
2 million tons per year AV

Fig. 1



Petroleum
Petroleum
121 J 1 million t per year AV
111 J 2 million t per year AV
Light gasoline 1/1
Light gasoline 1/1
114 J Pentane removal
Hexane distillate 2/2
Heavy gasoline 1/2
Heavy gasoline 1/2
112 J Reformer
Ref. gasoline
135 J Aromat. extract.
Benzene, toluene
303 J Aromatics storage
Toluene
Benzene
Heavy gasoline 1/4
Pentane distillate 2/4
Heavy gasoline 1/4
Fore-run, paraff. gasoline toluene, xylenes
300 J Gasoline blending
Ref gasoline 3/5
Pre-blended gasoline
301 J Ethylation plant
Imp. gasoline
Motor gasoline
Chem. industrial gasoline
Liquefied gas
Liquefied gas
302 J Liquefied gas stor.
Liquefied gas
H2-rich gas
Petroleum and gas oil contng. sulphur 1/3
Petroleum and gas oil contng. sulphur 1/3
113 J Gas oil desulphurizer
Hydrogen sulphide 4/5
Hydrogen sulphide 5/5
134 Claus
Sulphur
TSZ, and sulphur-free gas oil 4/5
Petroleum and gas oil 1/5
Petroleum and gas oil 1/5
Gas oil 5/5
304 J Petroleum, gas oil
TSz
Sulphur free gas oil
Sulphur cont. gas oil
H2-rich gas
Paraff free light oil, heavy dist. refined, residual oil refined 4/4
126 J Hydrofining
Spindle oil, engine oil dist., fine raff I, II
141 J Oil blending
Spindle oil distillate
Engine oil distillate
Spindle oil refin.
Engine oil
125 J Methyl-ethyl ketone
Light paraffin. distill. 1/3
Light paraffin. distill. 1/3
Heavy distillate, residual oil ref. 3/3
Goudron
Goudron 1/1
Heavy paraffin distill. 1/2
Residual oil 2/2
Heavy paraffin distill. 1/2
123 J Phenolic lube oil refining
Light paraffin. distill. 1/3
Heavy distillate, residual oil ref. 3/3
Light paraff. distill 1/3
124 J Paraffin remov. MEK extraction
Gatch I-II
Gatch I-II
131 J Paraffin manuf.
Ref. paraffin
Bitumen 2/4
Goudron 1/4
Goudron 1/4
132 J Bitumen blower
Bitumen
Gatch oil 5/5
Gatch I-II, petrolat 4/5
Gatch I-II, petrolat 4/5
Oil distillate 3/5
Goudron, light, and heavy paraffin. distill. 1/5
Extracts I-II 3/5
Goudron, light, and heavy paraffin. distill. 1/5
305 J Fuel oil blending
Light sulph. contr. fuel oil
Goudron

Fig. 2

The gas oil distillates from the distillation plant pass through a desulphurizer plant where sulphur compounds are converted into hydrogen sulphide with the hydrogen obtained in the reformer plant. From this hydrogen sulphide elementary sulphur is produced in a Claus plant.

The fuel oil desulphurizer is suitable also for the desulphurization of jet fuels.

The raw stock of the lubricating oil manufacture are partly the goudron residues of distillations and partly paraffinic cuts. Goudrons are treated in propane asphalt extraction units to yield bitumen and heavy paraffinic oils. Paraffinic oils, after solvent (phenol) extraction, are subjected to treatment for the removal of paraffin.

Paraffin removed is separated from oil by a solvent extraction treatment and then subjected to refining. Oils free from paraffin, after hydrofining, arrive in the blending plant where the products are finished. The network model of this combine is shown in Fig. 2.

The network model of the plant system without an intermediary tank park has to be studied from two aspects:

1. for the continuous operation of the system,

2. for the starting up and closing down operations of the system; the parameters for the system must be known for both conditions.

Partly for the construction, partly for the evaluation of the network already constructed, the following must be taken into account.

Continuous operation of the plant system

Given product part times, or given plant times, pertain to processes where given per cent composition of production is to be maintained.

When calculating with unit processing time, the lengths of pathways in the network will differ, this will express percentages of the various capacities.

The capacities needed for the individual plants or the correlated mutually proportional capacity ranges derive from the technological process-times referred to the unit mass of starting materials of each plant.

Determinant is the first plant (AV) of the system.

The necessary range of capacity of a plant is a function of the starting material requirement, or of the range of capacity, of the receiver plant or plants.

There is a strict correlation between the respective capacities or capacity ranges of the individual plants.

Capacity ranges serve to import flexibility to the system.

For such a flexible ("labile") system that needs constant supervision and control, and of which the operational limits are given in a pre-set programme, regulation "in every second" of time can amply be provided for by computer speed.

Co-ordination of the entire system makes regulation by computer according to a pre-determined programme imperative.

Co-ordination of capacities at every instant is not absolutely necessary, it suffices if this is assured for recurrent periods. In such cases product proportions vary (starting materials coming from several places). Periods may be different.

Within given ranges of capacity also the technological process (operation) may change.

The co-ordination of capacities, or of ranges of capacity, basis of the programme, should be taken into account as soon as at the plant design stage.

For continuous operation, the necessary range of capacity is the sufficient range of capacity. The lower limit of the capacity range is defined by the economy of the entire system.

A change of capacity (within the given range of capacity) at any operation of the plant operation sequence affects the entire system both forwards and backwards.

Starting up and shutting down of the system

The conditions for the start up of the plant next on line must be assured by the co-ordination of the capacity ranges.

The point in time of the start of the plant next on line, of the delivery of the intermediary product or of the receipt of the substance to be processed, depends upon the running to the full capacity of the technological process in the plant in question; upon the points in time when the products appear.

The point in time of an event is the time when any plant delivers that quantity of product which suffices for the starting up at lowest capacity of the plant next on line.

As a compromise, during start-up operation, ratios of part-products, or quality of part products, may differ from the final conditions prescribed for continuous operation. If this cannot be allowed, then certain part-products must be temporarily retained or storage space must be provided for them; this can be achieved by an adequate modification of the technological process or by utilizing an adequately dimensioned pipe system for temporary storage.

Similar conditions prevail when the system is to be shut down.

Network model of the plant system

The symbols used in a network model may be the following:

× event point of time when a product, or a substance to be processed, is delivered or received,
——→ activity, a technological process that consumes time,
- - → apparent activity delivery of a product or of a substance to be processed, that does not consume time in a continuous operation.

Event

With the exception of the first (starting) and of the last (terminal) event, any event is a starting and a terminal event at the same time; it is a terminal event for those that precede and a starting event for those that follow it.

The numbering of the events is such that along the lines of operation it always leads from an event with a lower number to one with a higher number.

The digit written above the symbol of the event indicates the earliest possible point of time at which the preceding operation or operations can be finished; this is at the same time the earliest possible time at which a subsequent operation or operations can begin.

The digit written below the symbol of the event indicates the latest acceptable point of time at which the preceding operation or operations must be finished; this is also the latest acceptable point of time at which a subsequent operation or operations must begin.

Where these two digits differ, the difference between them indicates reserve time. If the event happens within this interval then the time of final termination is not affected.

Where these two digits are the same, no reserve time is available, thus from the point of view of the final term the event lies on the critical path since its delay delays also the final termination.

Activity

The sign written above the arrow that symbolizes an operation refers to, or names, the technology of the plant in question. The digit below the arrow indicates the time needed for the processing of the mass of substance apportioned to the plant. An operation lasts from the starting event till the terminal event.

Apparent activity. Apparent operations indicate the delivery of products. Above the arrow which symbolizes such an apparent operation the name of the product is written. In a continuous operation no time is consumed by these.

If capacities are co-ordinated, any given plant receives that mass of substance it can process.

However, at start-up operations of the system the necessary composition of the substance to be processed may not be available because the substances arrive from various places and at various times to the individual plants. To express this possibility, after the name of the substance a vulgar fraction is written, of which the numerator indicates the earliest possible time of the availability of that substance and the denominator indicates the still acceptable latest moment of delivery.

What has been said in connection with the similar time data of events, is valid also here, thus where the value of the fraction is less than one, the product is delivered earlier than the terminal event requires it and reserve time is available which necessitates either retention or temporary storage. In the contrary case, the necessary composition of the substance to be processed cannot be assured before the process does not operate continuously.

Product delivery between plants where several products are transferred, is noted by a single apparent operation according to the rules of network construction.

In the network, the digit written after the name of the end product gives the number of the various paths along which the terminal event for a given product can be reached from the starting event. The higher this number the more complicated the production of the substance.

List of activities. The list of operations is an organic part of the network. This list contains the symbols of the operations, the starting and the terminating event of an operation (in the sequence of the starting events), the time needed for the operation, the designation of the operation, the points of time for the possible earliest and acceptable latest beginning, for the possible earliest and acceptable latest ending of an operation, and the reserve times.

In the present instant, as the first step the through time for the network was calculated according to the critical path method (CPM).

On the basis that plant capacities are given, and that within unit time the individual plants can continually process that mass of material which is their portion from the mass of material continuously fed into the plant system within unit time, time data were assumed as being uniformly one, or unity.

This condition being taken into consideration, it can be stated from the network that the system can be operated continuously, without a tank park of intermediary storage. This state is not disturbed by the fact that some of the finished products appear earlier than at storage prior to delivery.

However, deviation of the capacity of whichever plant from this given capacity affects the mass of substance receivable and deliverable in unit time, and thereby affects product composition. By classical means this problem cannot be solved but by intermediary storage.

The starting up of the plant system cannot be accomplished through the operation of the plants at their given capacities because each product emerges at another time. It seems to be more advantageous for both cases to take into account, instead of fixed capacities, such ranges of capacities within which a co-ordination of capacities assures that disturbances in the course of continuous operation can be offset, and the system can be put on stream.

Based upon capacity-ranges, it is more advantageous to calculate the entire programme by the PERT method.

Then for the triple time estimates of the PERT method, i.e. for the optimistic (a), the most probable (m), the pessimistic PERT ESTIMATE (b), the time data deducible from maximum, most probable, and minimum plant capacity can be substituted, respectively.

From these the time to be expected is:

$$\bar{t} = \frac{a + 4\,m + b}{6}$$

What, in the PERT method, expresses the uncertainty of the occurrence of an event (variance or scattering) gives, in the present instance, that range of capacity by the help of which co-ordination of the individual members of the plant system becomes possible or by which the system itself can be controlled.

If, from technology or other causes, for any plant a given fixed capacity, i.e. time without scatter, must be taken into account, then for this plant this time without scatter, belonging to the given capacity is introduced as a restrictive factor and the programme is calculated throughout on this basis.

As further tasks the following might be noted.

a) Determination of capacity-ranges.

b) Completion of a network model with the consideration of the auxiliary substances of the technological process.

c) Construction of a computer programme.

d) Study of the effects of possible variations of the plant system.

Reference

1. KORACH, M.: Systématisation du Génie Chimique. XXXIV^e Congrès International de Chimie Industrielle Beograd, 22—29 Septembre, 1963. Recueil des Conférences Plénières, Beograd 1965, 81 p.

Summary

Among the tasks of general chemical technology, process engineering assumes an ever increasing importance. Along with the progress of process engineering went the studies which sought also a method for representing process flow in chemical industrial plants. In this Department, academician M. Korach was the initiator of the use of technology graphs, the development of which resulted in the adoption of a system network for representation purposes. As an example, the technology of a petroleum processing work with a capacity of 3 million tons per year is represented by the usual block-scheme and is compared with its network system designed according to the CPM method.

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