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## DESIGN CONSIDERATIONS IN SOLVENT RECOVERY

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## PRINCIPLES OF ADSORPTION RECOVERY

Adsorption, which is the ability of solids to collect at their surface gases or vapours which come into contact with them, has been known for some time. The amount of adsorption which takes place on most solids is small because the surface area available is limited, but a number of specialized materials have been developed which have high surface areas per unit volume and consequently are able to adsorb substantial quantities of gas or vapour. Materials of this sort include activated carbon, activated alumina and silica gel, all of which allow adsorption because they are porous solids containing a large number of small capillaries or micropores which provide the surface area for adsorption.

Different gases or vapours are adsorbed to different extents upon the surface of the same solid at a given time; the theory of adsorption recovery is based upon this rate differential. It is possible to remove and to recover the adsorbed materials from the solids by various means. This two step process of adsorption and desorption (removal from the surface) is the basis of every adsorption recovery process. The two best methods of adsorption at a solid surface are physical adsorption and chemical adsorption.

In physical adsorption, the attraction between the vapour and the solid surface is caused by the intermolecular Van Der Waals forces which exist but which are themselves weak and randomly oriented. These forces ultimately lead to the condensation of the gas or vapour into a liquid when they and the capillary pressures applied within the pores of the solid become sufficiently large. On a smooth surface the adsorption caused by these forces is limited to a single layer of only a few molecules thickness, but in a capillary structure, as is found in an adsorptive material, the quantity is substantially supplemented by capillary condensation.

Chemical adsorption works entirely differently. The binding forces between the solid and the gas are substantially stronger than in physical adsorption and are comparable with those leading to the formation of chemical compounds. In fact, chemical adsorption may be regarded as the formation of a sort of surface compound. It is seldom reversible and consequently is a nuisance when it occurs during a recovery process. Considerable energy must be put in to desorb a chemisorbed material and, on occasion, the material that is evolved on desorption is not the same as that which was adsorbed. For example, after oxygen is adsorbed on charcoal at 100° centigrade, heating can cause the desorption of carbon monoxide. Chemisorption is normally complete when a single molecular monolayer has been deposited over the entire surface of the adsorbent.

All adsorption processes are accompanied by a release of energy. In the case of physical adsorption, the amount of heat released is somewhat greater than the heat of condensation of the gases or vapours being adsorbed, and an additional amount of energy is involved due to the direct attraction between the surface and the gas. In the case of chemical adsorption the heat release is approximately the same as the heat of

chemical reaction for the particular surface reaction involved. Thus, during adsorption, a temperature rise is always observed and in a number of cases it is necessary to provide facilities for removal of this heat. To desorb the gases, it is, of course, necessary to replace this energy. This replacement constitutes a substantial part of the total cost of recovery in any process using this method.

The adsorption of a gas onto a particular solid is quite specific and depends on temperature, pressure, the nature of the solid and the gas, and the concentration of the gas. Equilibrium curves can be plotted for this relationship and exist in the literature on the topic. These curves are normally plotted as adsorption isotherms, giving the relationship at equilibrium between the concentration of gas on the solid and concentration of gas in the feed stream. Some typical adsorption isotherms are shown in Figure 1. Similar equilibrium curves can also be plotted for the desorption process and some examples of these are shown at Figure 2.

It is fortunate that differential adsorption takes place from mixtures of gases. This means that if a hydrocarbon gas mixture, for example, is passed over a solid surface such as activated carbon, the different components in the gas stream will be adsorbed not only to different equilibrium levels, depending upon their concentrations, but also at different rates. Ultimately, it will be found that some components will start displacing others, in general the heavier component displacing the lighter. Based on this principle, it is possible to design adsorption systems for the selective recovery of desirable components, as is carried out for example in natural gas processing. As an example, in the adsorption of a mixture of methane, ethane and propane from an air stream, the first to be adsorbed will be the methane, but this will subsequently be displaced by ethane which in its turn will be displaced by propane. At any point in time, a specific mixture of these will be found on the carbon. This is effectively the same principle as is found in a chromatographic column applied on an industrial scale.

A wide range of adsorbents, particularly activated carbons, are available on the market today. The commonest forms of carbon are either coal based or coconut shell based and these do have somewhat different characteristics. The growing understanding of the adsorption process has led to the ability to tailor the properties, such as pore size distribution and overall activity of the adsorbent, to suit the particular separation that is required. This has been accompanied by much development in the last few years of the mechanical contacting equipment that is available to carry out these separations, and as a result of these parallel developments, it is now possible to carry out with very great efficiency a large number of complicated separations. Some indications of these will be given in the remainder of the paper.

## CONTACTING EQUIPMENT, FIXED BED AND FLUID BED SYSTEMS

Simplified flowsheets of conventional fixed bed and the more recently developed fluidised bed system for solvent recovery plants are shown in Figures 3 and 4.

The fixed bed plant consists of a number of vessels containing activated carbon into which the solvent laden gas stream is introduced in turn. The solvent laden stream is allowed to flow through the carbon bed, the solvent adsorbed onto the activated carbon and the solvent free air discharged into the atmosphere. This process continues until the carbon in the vessel is saturated with solvent up to a level approaching the equilibrium concentration for the particular inlet stream, at which stage, known as the breakthrough point, the air or airstream is transferred to another adsorption vessel. Steam, or some similar desorbing medium is introduced into the loaded vessel to drive off the solvent from the carbon, the steam-solvent mixture is collected and condensed and may then be decanted, distilled, separated and purified as appropriate

FIGURE 1.  
ISOTHERMS AT 90° F FOR VARIOUS  
SOLVENTS ON ACTIVATED CARBON.

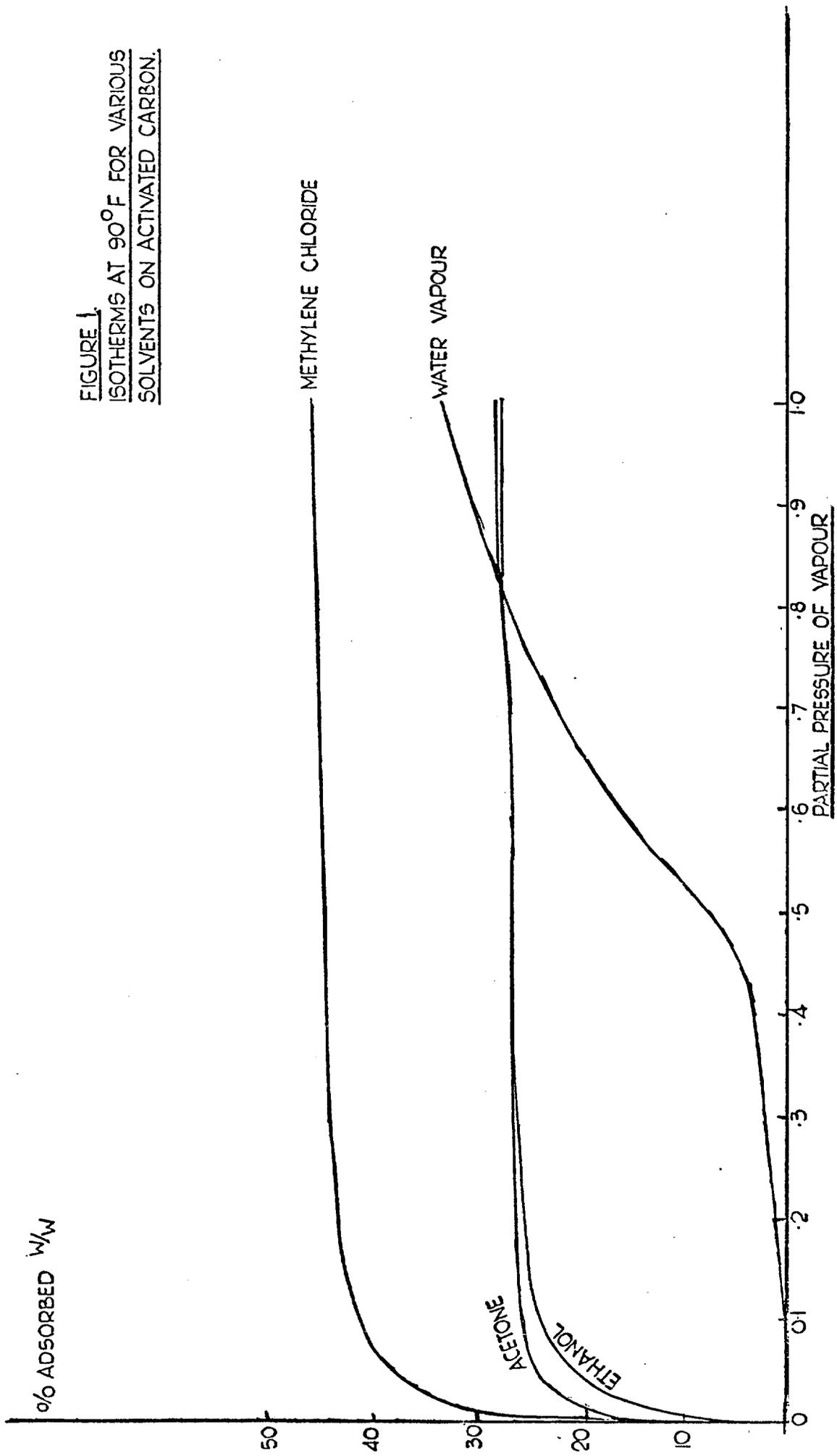
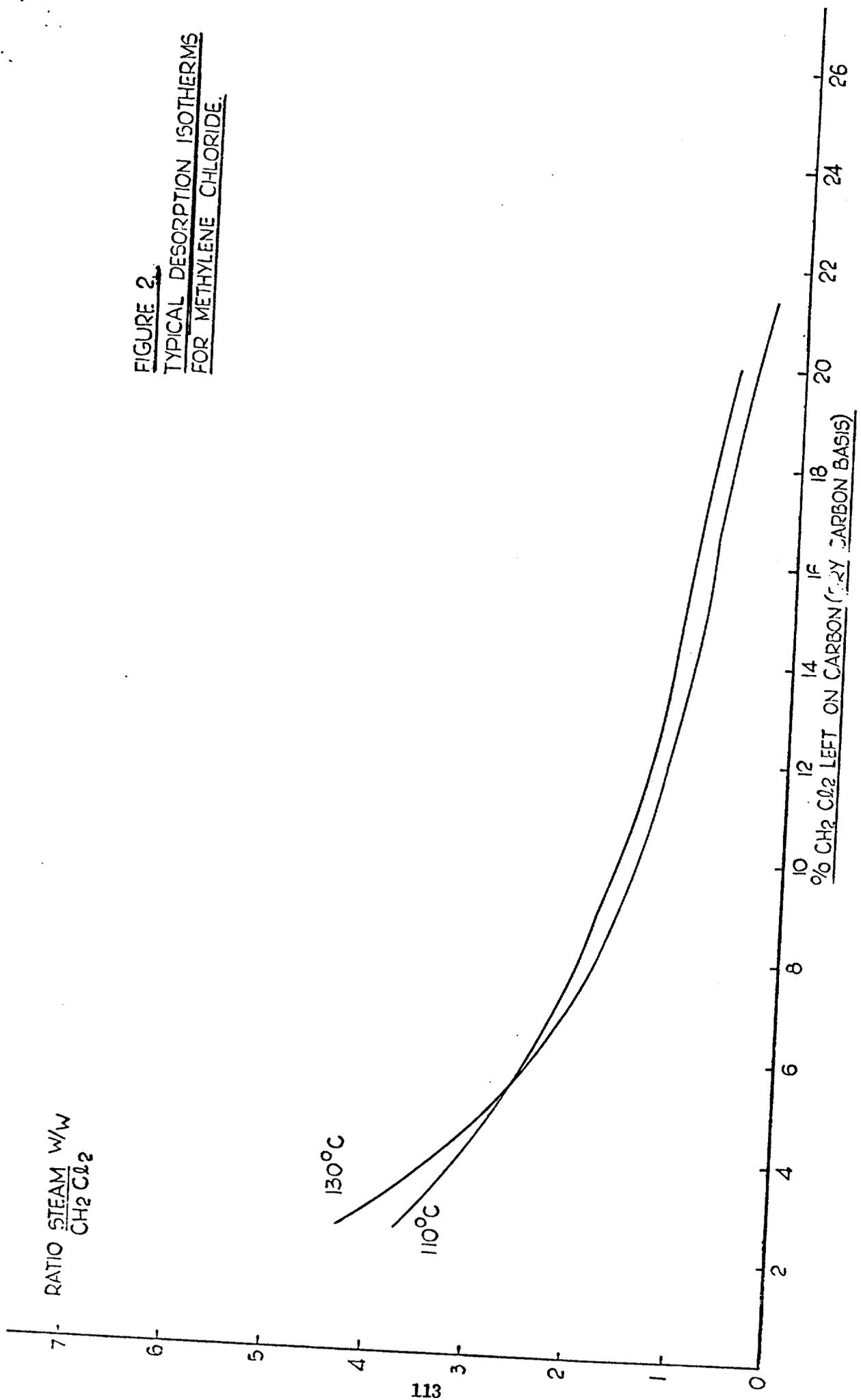


FIGURE 2.  
TYPICAL DESORPTION ISOTHERMS  
FOR METHYLENE CHLORIDE.





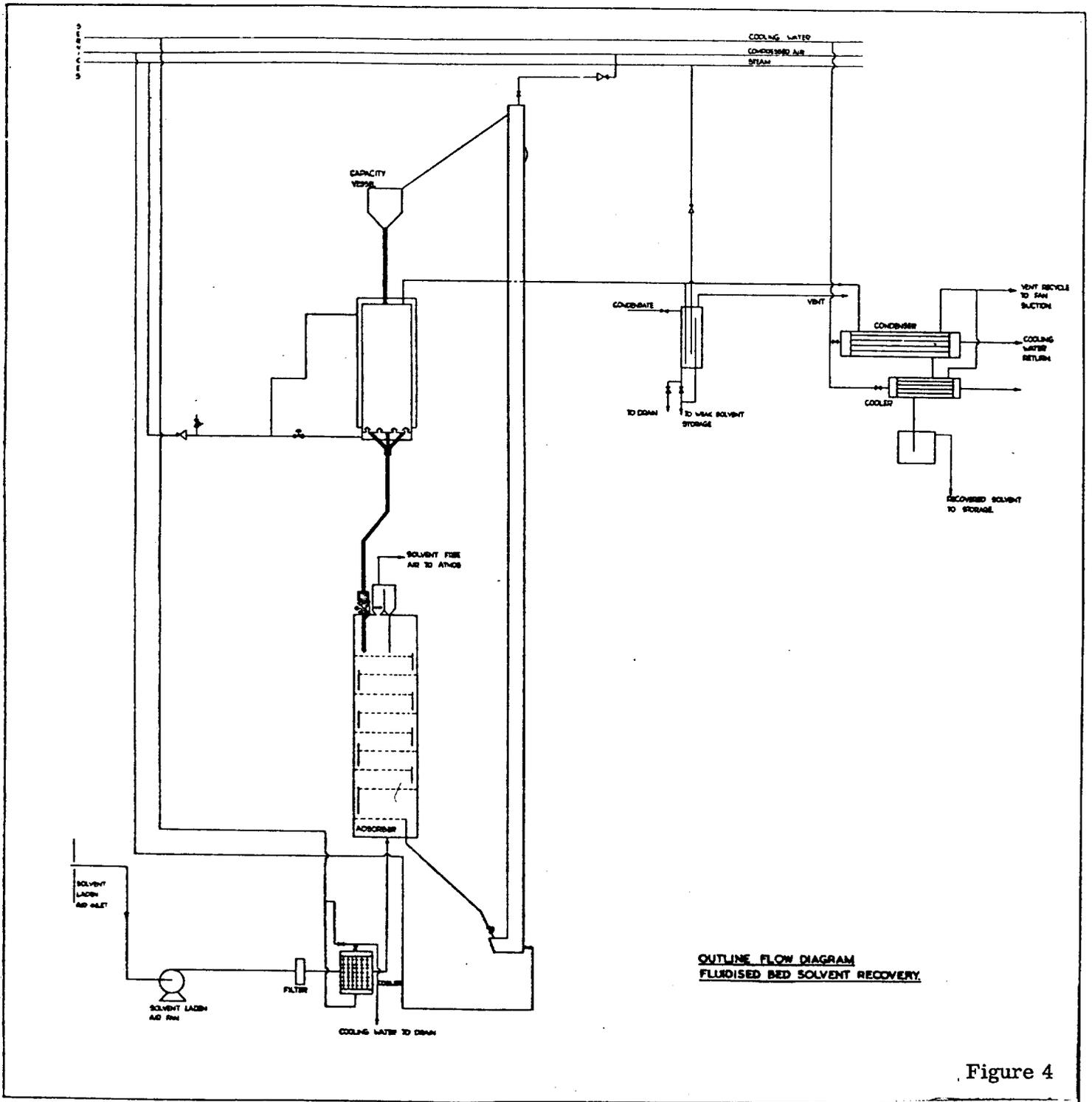


Figure 4

for the particular system. Any number of vessels (within reason) may be installed in parallel. Very large installations using this process have been built. On small units it is common for the switching of air and steam to be carried out automatically by means of a cycle controller or some system of this sort. Even so, this system is basically discontinuous and does not provide a steady flow of recovered solvent for onward processing. A disadvantage of the fixed bed system comes from the fact that the solvent laden stream progresses through the bed in an uneven manner, and consequently, causes a significant loss of solvent from the bed before it becomes fully saturated. A further problem comes from the fact that the velocity of air flowing through the bed of carbon has to be kept fairly low to keep the pressure drop within bounds. Consequently, when large airflows are to be handled, large numbers of beds are required to provide an adequate flow area. Thus, in big applications, the fixed bed plant requires a very large ground area.

Partly because of these considerations the fluidised bed approach for solvent recovery was developed in England, toward the end of the 1950's. In this process, the solid adsorbent, again activated carbon, is circulated through an adsorber and a stripper vessel. The process is in many ways very similar to a liquid phase adsorption system.

In this process, the solvent laden air or gas stream is passed upwards through the adsorber vessel which contains a number of shallow fluidised beds of activated carbon. The solvent is progressively adsorbed onto the carbon, and the solvent free air is discharged through dust collectors to the atmosphere. The loaded carbon passes from the adsorber into a mechanical elevator and is carried to the top of the plant where it is discharged through a capacity vessel into a desorption vessel. In this vessel it is continuously contacted in a counter-current manner with live low pressure steam and the steam-solvent mixture is collected at a constant rate from the top of the vessel. The stripped carbon is returned to the top of the adsorber thus completing the cycle. The steam-solvent mixture is led away to condensation and separation as in a fixed bed plant.

This process has a number of advantages compared with the fixed bed process. It is fully continuous and all contacting is genuinely counter-current, thus giving the maximum mass transfer advantage. The adsorber in particular may be built with any reasonable number of trays in it, and it has been found from experience that each stage acts effectively as one theoretical mass transfer stage. Thus, efficient recoveries may be achieved from very low concentrations of solvent in inlet air. Since a fluidised bed possesses the inherent properties of very good mixing and flow, all the carbon is evenly loaded with solvent. This loading takes place up to a higher level than in the equivalent fixed bed system. The benefit of this is felt in the desorption stage where significantly less steam is required in desorption than in the equivalent fixed bed operation because of the higher loadings. This lower steam requirement leads to a higher concentration of recovered solvent liquor and simplifies the problem of purification. The process is completely continuous, automatically controlled, and requires a minimum of supervision. The fluidised bed approach allows much higher superficial velocities to be used than in the fixed bed plant, by a factor of four. This means that in the larger applications, the size of the equipment can be kept within reasonable bounds. Fluidised bed plants have been built and are operating commercially on air flows as large as 450,000 cfm, a flow which would be inconceivable to handle in a fixed bed plant. But the application of these plants is not limited to very large flows and other units are operating or are under construction for applications as low as 10,000 cfm. A comparison of the properties and advantages of the fixed and fluid bed systems is presented in Table 1. These processes both have a part to play in solvent recovery and atmospheric pollution control, and the correct selection of process is a matter of detailed examination at an early stage in the assessment of a particular problem.

Table 1

COMPARISON OF ADVANTAGES  
FIXED BED AND FLUIDISED BED RECOVERY PLANTS

FIXED BED  
RECOVERY PLANT

FLUIDISED BED  
RECOVERY PLANT

Large turn-down giving flexible operation.

Exceptional contacting between solvent and adsorbent giving very high efficiencies.

Easily built as manually or automatically operated plant.

Complete continuous automatic operation, with minimum labor requirements.

Relatively inexpensive in capital cost at small sizes.

Competitive in cost for the medium and larger installation.

No use of sophisticated instrumentation (an advantage in the smaller organisation where an instrument mechanic may not be available).

Low stripping steam usage (about half that of equivalent fixed bed plant).

Low ground area requirement

High concentration of solvent in recovered aqueous liquor simplifying onward processing.

Inherently safe even with highly inflammable solvents.

FACTORS AFFECTING THE CHOICE OF SOLVENT RECOVERY SYSTEMS

1. Air Flow

On either fixed bed or fluid bed solvent recovery systems, the capital cost of the plant is primarily influenced by the air flow to be handled. In both cases the size of the plant is determined and limited by the superficial velocity of air that can be handled in it. Consequently, there is a considerable advantage in keeping this air flow at a minimum. In any consideration of solvent recovery as part of an air pollution problem, it is necessary to consider the associated ventilation problems of the solvent evolving process as a whole. In many cases, by modification to the ventilation and enclosure arrangements of machines and working spaces, it is possible to reduce radically the air flow to be handled and consequently to effect a substantial reduction in the first cost of the plant or equipment to be installed.

## 2. Concentration of Solvent

A second advantage of reducing the air flow from the process is that at the same time the concentration of solvent in the air stream is increased proportionally. This leads to a higher concentration of solvent being adsorbed onto the carbon adsorbent, and leads to overall process economies. As a general rule, the target is minimum air flow and maximum solvent concentration.

In a considerable number of practical cases, the limiting factor on solvent concentration that can be achieved is the lower explosive limit of the solvent in an air stream. Table 2 gives some typical LEL figures for common industrial solvents. Normal industrial practice suggests that it is safe to work consistently at concentrations of between 60% and 70% of the LEL, but it is unusual to work any nearer than that to the explosive limit. A number of companies insist on backing their normal ventilation with an automatic auxiliary system so that in the event of failure of a ventilation fan, they do not lose the extraction rate from their process and find themselves in an explosive situation.

Opinions vary widely on how close one can operate to the LEL and in this country the tendency is to work at rather lower concentrations than is the normal case in Europe. Nonetheless, in a properly designed ventilation system, there is little reason that one should not work at the levels suggested, namely 60% to 70% of the LEL. The economic advantages to be obtained from these levels are considerable and it should be remembered that there now exist a number of reliable instrumentation and control systems to give ample warning of any deviation from a safe condition.

## 3. Solvent Type

In general the type of solvent does not make a great deal of difference to the choice of recovery system. It is somewhat easier to recover low boiling solvents than it is to recover high boilers but even this is a problem which can be readily overcome. The only things to be particularly careful of are those solvents which on an active carbon surface tend to decompose. The energy levels involved and the highly active nature of the carbon surface tend to make it act as a catalyst in a decomposition process, which can, on occasion, lead to unfortunate side effects. An example of this tendency occurs in the recovery of carbon-disulphide which tends to decompose to some extent on a carbon surface to give elemental sulphur and sulphur compounds. These compounds progressively tend to poison the carbon and steps have to be taken to overcome this tendency. Another material which tends to decompose on carbon is dimethylformamide. This tends to break down to dimethylamine and formic acid, a reaction which is somewhat speeded up on the carbon surface from its normal rate in a test tube.

A point which must always be borne in mind in regard to solvent type is the ultimate method of working up of the solvent to a reusable state. Solvents basically can be divided into two groups: those which are miscible with water and consequently are recovered from the adsorption process as an aqueous solution, and those which are immiscible and which hence may be recovered in a high degree of purity by decantation from the recovered liquors. This latter case is straightforward to handle. The case of the miscible solvents, however, requires distillation equipment. It is at this point that the fluid bed process with its continuity of operation offers an advantage over the fixed bed plant, in that a distillation column may be fed with a steady flow of relatively high concentration feed rather than with a discontinuous flow.

Table 2

LOWER EXPLOSIVE LIMITS FOR  
SOME COMMONLY USED INFLAMMABLE  
INDUSTRIAL SOLVENTS

SOLVENT	LOWER EXPLOSIVE LIMIT* % V/V IN AIR @ 20° C.
Acetone	2.55
Methyl Ethyl Ketone	1.81
Iso Propyl Alcohol	2. 0
Benzene	1. 4
Toluene	1.27
Ethyl Acetate	2.25
Iso Propyl Acetate	2. 0
Di-methyl Formamide	2. 2
Di-methyl Acetamide (@ 100° C.)	1. 8
Di-ethyl Ether	1.85
Methyl Alcohol	7. 2
Ethyl Alcohol	4. 3
Carbon disulphide	1. 2

\*NOTE: These figures are indicative only, and some variations occur between different references.

#### 4. Operating Continuity.

The majority of processes tend, even now, to be discontinuous in operation. Social considerations dictate that even an expensive capital plant is run on a maximum of two shifts rather than on a three shift basis. In a number of cases this has proved to be the overriding consideration in the choice between a fixed bed or a fluid bed plant because the fixed bed process, being itself inherently discontinuous, is readily suited to a process in which the solvent is evolved in that manner. The fixed bed plant has a large turn down ratio. The fluid bed process, on the other hand, is a continuous plant and requires continuous operation. Consequently, it is generally not well suited to those operations which only take place for perhaps 18 hours out of the 24. An example of the first case is in the automobile industry where painting of car bodies, an operation which involves very large quantities of solvents, takes place throughout the world on a two shift basis. It would be relatively difficult under these circumstances to design a fluidised bed plant to cope with this duty. This would apply even though other considerations, in particular the volume of air to be handled, would seem to make the fluid bed plant most suitable. On the other hand, in the synthetic fibre industry the manufacture of rayon is not only continuous 168 hours a week, but in many cases continuous for several years at a time. Under these circumstances, the streams to be handled are eminently suitable to a fully continuous process. As a general rule, if the solvent laden air stream is evolved for a period of less than about 60 hours continuously it is probably more suitable for a fixed bed than a fluid bed process. Conversely the longer run streams are very likely more suitable for the fluid bed run than for the fixed bed. However, it should be remembered that this is a gross generalisation, the assessment of which is that the most suitable process must be done by an expert under the particular circumstances prevailing in any specific case.

#### CARBON FOULING AND REGENERATION

During its working life the activity of the adsorbent in a recovery plant progressively declines. This is caused by the adsorption onto the carbon of fairly small quantities of strongly adsorbed non-volatile compounds. These may arise either from decomposition or a polymerization of the materials being recovered or they may be present as contaminants in the incoming airstream. An example of both of these occurs in  $CS_2$  recovery from the viscose process where, as was previously mentioned, some of the carbon disulfide breaks down to give sulfur and sulfur compounds which contaminate the carbon, not removed by the normal desorption process with low pressure steam. Hydrogen sulfide is also associated with the  $CS_2$  evolved from the viscose process and some of this is adsorbed onto the carbon. On adsorption it is immediately oxidised to give sulphur compounds which remain on the carbon and are relatively involatile. Unless carbon is regenerated its activity will quite quickly drop to a level at which it is virtually useless.

In a fixed bed plant, regeneration may be carried out in one of two ways. The carbon charge may be completely removed from the plant and returned to the carbon manufacturers for reactivation, a process which is expensive, dirty, time consuming and a considerable nuisance in that the plant has to be out of commission for a long period while the carbon charge is being changed. Alternatively, the carbon has to be regenerated in situ. In the case of the carbon disulfide process, the only moderately satisfactory way that has been found of doing this is by liquid washing the carbon with a sodium sulfide solution. It is a somewhat hazardous and unpleasant process, and has caused a number of accidents in the past. In either method a break in production is involved.

In the fluid bed process, regeneration is relatively straightforward because it is possible to take a side stream of carbon from the main circulation, regenerate it and return the reactivated carbon to the main circuit. By this means, an adequate level of activity is maintained on the carbon in the main process. This is the method adopted on fluid bed CS<sub>2</sub> Recovery Plants, where a side stream of perhaps 5% of the total circulation is taken through a high temperature process and returned to the process, its activity restored. This technique, which does not in any way affect the operation of the main plant, has been run for a number of years satisfactorily.

The same approach may be applied to other processes. For example, solvent recovery plants are frequently affected by the presence in the incoming air stream of plasticisers, spinning oils and similar products. These very frequently polymerize on activated carbon and reduce the overall activity. In the fluid bed process it is perfectly reasonable to treat continuously a relatively small side stream and so to maintain a satisfactory level of activity throughout the plant.

## SAFETY ASPECTS

Brief mention has already been made of certain aspects of recovery processes when discussing concentrations of solvent. The majority of solvents that are handled are inflammable or explosive and in many cases also toxic. Therefore it is necessary to pay considerable attention to the safety features of handling them. In this area, the fluid bed process on the whole shows considerable advantages over the fixed bed plant. In a fixed bed unit, because of the pattern of air flows, tendency of the bed to segregate and compact, there is always some tendency towards channeling through the bed. Adsorption, too, in a fixed bed plant, tends on occasion to be rather uneven. Bearing in mind the high energy evolution rates that occur in adsorption processes, there is always some risk in a fixed bed plant of hot spots occurring which may ultimately lead to fires. A number of instances of this have been reported. Also there are certain solvents which appear on carbon to have a rather low ignition point. Examples of this are methylethylketone and tetrahydrofuran. In the fluid bed process, which is inherently isothermal, the risk of hot spots is completely eliminated and consequently the safety factor is much improved. Provided that the concentration of solvent in the incoming air is kept below the lower explosive limit, there is no risk in either process of an explosion or an explosive concentration occurring in the adsorber, provided that the carbon fed to it has been adequately stripped. In the case of the stripper or the stripping stage of the process, this is also inherently safe because at all times the contents of the vessel will be completely steam blanketed. The condensation system is normally run slightly above atmospheric pressure to ensure that any leaks are from inside to out. In the fluid bed process, as an added safety measure, when handling particularly dangerous chemicals such as carbon disulfide, facilities exist to inject inert gas to purge the system at suitable points of the circulation and ensure that an explosive concentration cannot under any circumstances build up.

Over a number of years the fluid bed process has been effectively developed as a fail safe system. Mechanical items of plant have been interlocked so that in the event of a failure anywhere in the system, which could conceivably lead to a dangerous situation, the relevant items of equipment are isolated, and the process streams are diverted until the dangerous condition has been avoided. It is not possible to do this with a fixed bed plant and the procedure here is to keep a careful and constant watch on the temperature of the carbon bed to give immediate warning of any abnormal condition. Normally, a series of temperature indicators and an alarm system would be installed in a fixed bed adsorption plant.

In the fluid bed process, the whole plant is coupled to an alarm annunciator system which is designed to give warning of any abnormal condition on the plant and warn the appropriate operators.

Experience has shown over a number of years of operation, particularly of the fluid bed process, that it is completely safe and presents no hazard in operation. The fixed bed process, if properly run is also an entirely safe and satisfactory plant. It is, however, vulnerable if errors are made in its operation, for example if the carbon charge is not regularly screened, graded and cleaned to ensure that there is no chance of channeling or bypassing taking place through the carbon beds.

## EFFICIENCY OF OPERATION

It is only quite recently that it has become possible to measure continuously the efficiency of a solvent recovery plant. This possibility has resulted from the development of adequate continuous chromatographic analysers. Even now, these are not widely employed and a large number of solvent recovery installations are still run on somewhat thin operational evidence.

In a fixed bed plant, the basic efficiency of operation will be governed by the amount of carbon in the system and the adequacy with which this is stripped during the desorption process. The solvent laden air leaving the adsorber will contain approximately the equilibrium concentration of solvent related to the residual solvent concentration on the carbon. Thus, to obtain a higher efficiency - better stripping, more steam is required. For the majority of applications in a well maintained fixed bed plant, efficiencies of 97% to 98%, defined as the ratio of solvent outlet to inlet concentration over the adsorber are quite easily achieved. To achieve better efficiencies than this frequently becomes uneconomical because it is necessary to run the plant on short cycle times to avoid excessive break-through at the end of the adsorption cycle, and it is necessary, for the stated reason, to use excessive quantities of steam in stripping.

In the fluid bed process, efficiency is governed by rather different factors. Again, the efficiency of stripping is important, but two other significant factors are the number of adsorption stages which have been installed in the plant - a feature which is taken care of during the design stage - and the applied carbon circulation rate. Basically, provided that the carbon is well stripped to increase the efficiency of the plant or to reduce the solvent outlet concentration, it is necessary only to increase the carbon circulation rate. However, beyond a certain point this means that the solvent loading on the fully loaded carbon leaving the adsorber also starts to be reduced, consequently leading to relatively uneconomical steam stripping. In a well run fluid bed plant, efficiencies of 99% measured over the adsorber are quite readily attainable.

Thus it can be seen that the efficiency at which a solvent recovery plant is operated depends basically on economic considerations. Assessment in individual cases must bear in mind the cost of the solvent, and also the cost of the services required to recover it at a higher efficiency. It is probably true that in the majority of instances justification of a recovery efficiency much above 98% is relatively difficult, although, for psychological reasons, a lot of managements insist on squeezing the last ounce out of their plants. Nonetheless, this calculation is not difficult to carry out and is one with which any reputable solvent recovery plant manufacturer will be pleased to assist his clients.

It is worth mentioning that in the fluid bed plant, it is very easy at any particular time to control the efficiency of the operation simply by altering the carbon circulation rate. This means that once the various parameters involved have been established, it is always a straightforward matter for the plant operators to run the plant at the most economic prevailing conditions, relatively difficult to do in a fixed bed unit in which alterations to a cycle controller may well be involved.

Very high efficiencies of solvent recovery over the distillation stages are easily achieved, for a price.

## CONTROLS AND INSTRUMENTATION

On a fixed bed plant, instrumentation normally installed is fairly simple. The key item is a cycle control which consists of an accurate timing mechanism and a series of valve actuators. In addition, it is customary to install flow controls on plant air and steam and a series of temperature indicators around the unit. The only other instrumentation customarily installed are temperature alarms in the carbon bed to warn of any inherent fire risk. On the fluid bed plant more instrumentation is normally used since it is a continuously operating unit. Apart from flow indication, and in some cases flow control of the incoming air, control of the steam flow to the stripper is essential. The level of carbon in the capacity vessel in the circulation system is also continuously monitored and coupled into a comprehensive alarm annunciator system which is installed to warn of any unusual happenings on the plant. A relatively recent development in this area has been the use of on-line analytical instruments which measure the solvent inlet and outlet concentrations to the adsorber. Recent experiments have shown that it is possible to couple the output from one of these analysers to the steam feed valve to the stripper and also to the carbon circulation rate control valve and by the use of ratio controllers to continuously optimise the flows of the steam and carbon on the basis of the solvent concentration. It is expected that this will substantially improve the economic operation of the fluid bed process in the future making it much more sensitive to variations in the solvent feed.

Both plants, if properly designed, require a minimum of process supervision. A fixed bed plant is normally reckoned to require approximately one man per shift for supervising plants even of large size. In the fluid bed process, because of the sophisticated alarm system installed, normally one man per shift is employed perhaps half his time. The remainder of his time he may readily supervise other plants. On the fluid bed plant his duties are primarily concerned with patrolling the plant on a routine basis and with making minor process adjustments as these conditions vary. Figure 5 shows a simple instrumentation layout for a typical fluid bed plant.

Distillation units installed with adsorption recovery plants are normally fully automatic and require minimum supervision on their own account.

Figure 6 shows a photograph of an instrument panel supplied for a large CS<sub>2</sub> recovery unit. This plant has been installed in Wales and is completely automatic. The whole plant is supervised by one man per shift who is not fully employed.

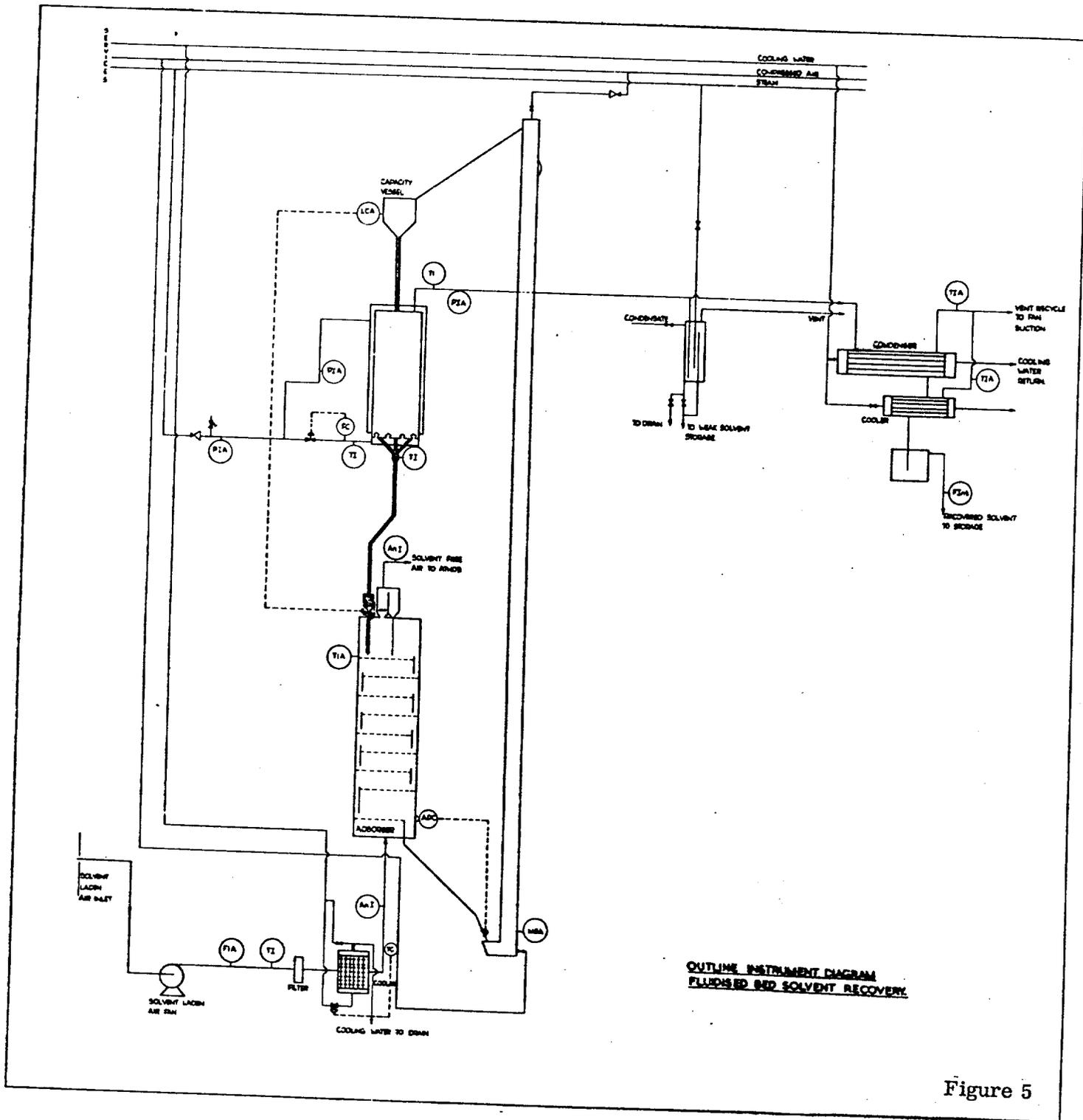


Figure 5



Figure 6. Fluidised bed carbon disulfide recovery plant instrument panel and control room.

## OTHER NEW APPLICATIONS FOR ADSORPTION TECHNIQUES

Until now only solvent recovery applications of adsorption have been discussed, but many other areas are open to this method. For example, in atmospheric pollution control there is no doubt that the ability of adsorbents to remove efficiently small quantities of noxious materials from large volumes of air, will be a most valuable tool. Legislation is pending in many areas of the world which will mean that organisations are going to have to spend substantial sums of money in reducing the emission of noxious materials from their industrial processes. Unfortunately, there is little or no economic return to be gained in atmospheric pollution control in the majority of instances, although there are a few exceptions to this. For example, in the Paint Industry, especially in application areas, recovery of the solvents from those parts of the process, while not necessarily giving a very encouraging rate of return on the capital employed, will at least show some return and might perhaps produce a process in which the operator can cover his running costs.

The Fluid Bed Process, with the capability of handling air flows up to a million cfm in a single train unit will be widely used in the future. Probably no other contacting method can efficiently handle air flows of this volume.

Another area in which adsorption technology is already being used and which seems to have a promising future is the separation of hydrocarbon gases. A number of fixed bed plants have been built to recover propane and higher gases from natural gas feedstocks using the selective adsorption approach mentioned. Adsorbents frequently react to a gas mixture in a different way from a conventional vapour-liquid equilibrium system and consequently it becomes possible to carry out separations which are relatively difficult by conventional processing methods. There seems again little doubt that this sort of development will show considerable increase over the next few years.

A third area in which application of adsorption techniques is likely to extend, is in the area of control of  $\text{SO}_2$  emission from power station flue gases. A method of recovery utilising basically the fluidised bed contacting approach has been under longtime examination in England and appears to have some prospects of success. The problem is to handle very large volumes of gases at relatively high temperature in which the content of  $\text{SO}_2$  is relatively small. Economically this problem has always proved unattractive, but there are hopes that an efficient process recovering large quantities of sulfur might now pay its way, particularly as world sulfur prices tend to rise. In any case public health requirements would seem to be leading towards the legislation which will demand control of  $\text{SO}_2$  emission, a major contributor to area air pollution.

## CONCLUSION

Adsorption is a tool that can be well used by the chemical engineer. Methods and experience have been gathered over the last few years while adequate methods of contacting solid adsorbents with gas streams have been devised for efficient recovery systems. Expert advice is still required in adsorption because of the implications on the design of other process units caused by the particular requirements of a recovery process. This information exists, however, and recovery processes will doubtless play an increasing part in industrial processes over the next few years.

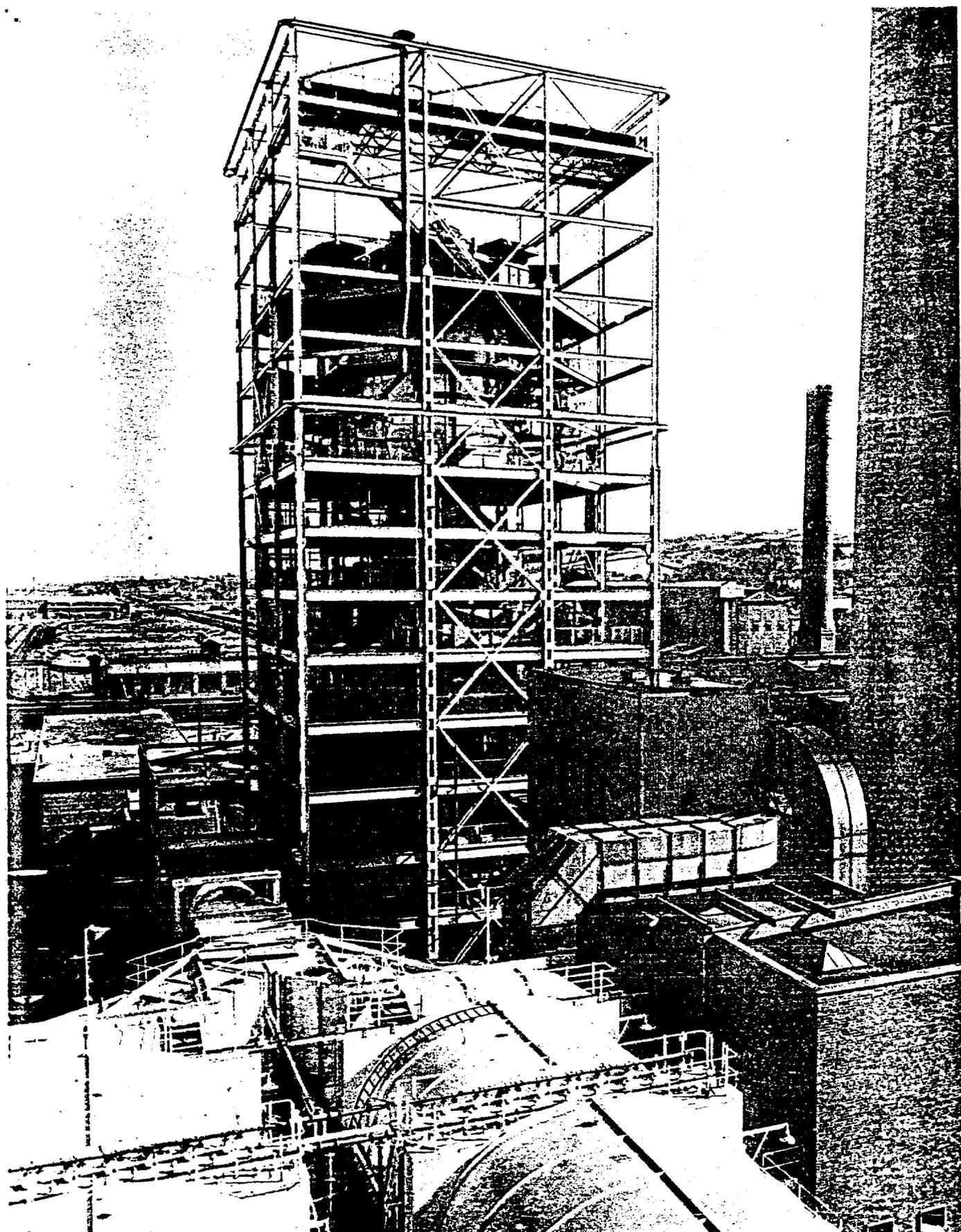


Figure 7 A large CS<sub>2</sub> recovery plant using the fluidised bed principle. The air flow is 250,000 cfm.

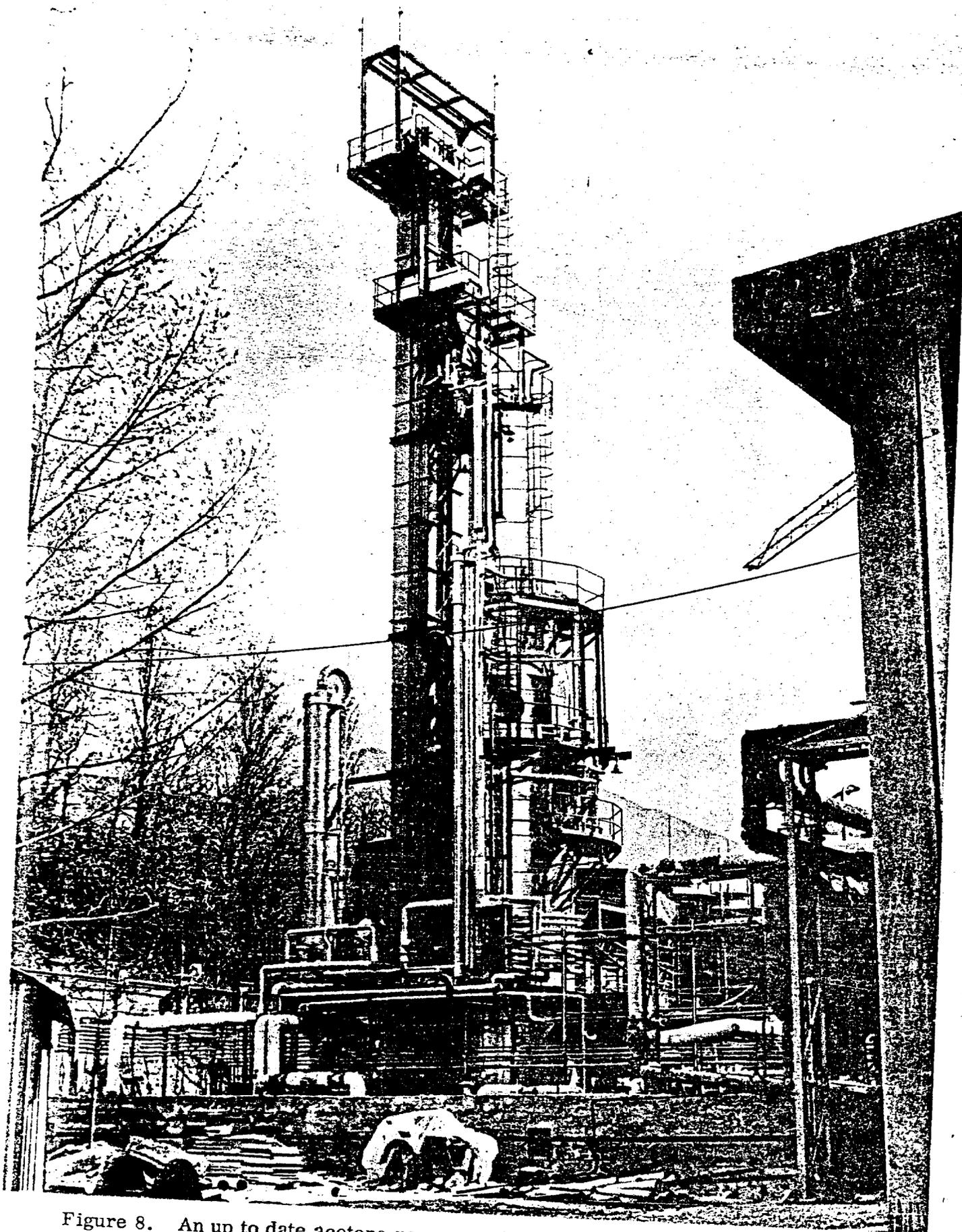


Figure 8. An up to date acetone recovery plant recently commissioned in Italy.