SALT WATER DISPOSAL

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INTRODUCTION

Disposal of oil field produced brines and associated waste water is not a new problem to the industry and much has been written about it as technical and trade journal literature will attest. Every method of disposal from haphazard discharge to open stream and tidewater, evaporation, and seepage to injection into subsurface formations has been employed.

The polluting aspects of disposal were recognized early and responsible operators began investigating disposal into saline subsurface formations as far back as 1936. Much of the earlier investigation work was done in East Texas and in 1938 the first salt water disposal well was put into operation in the East Texas Field. In 1939 an injunction suit was filed against many of the operators with properties in the southern part of that field to prevent pollution of the Neches-Angelina watershed. This suit foretold the end of haphazard disposal of salt water or any disposition that could potentially pollute fresh water sources. Although several alternates to surface discharge were tried, out of this suit came the now widely practiced solution of injection into subsurface formations. The related gathering, treating and mechanical problems brought about the formation of the East Texas Salt Water Disposal Company in 1942, a Texas Corporation, designed to serve operators in the field "without discrimination as to company or group". The effectiveness of this project in the East Texas Field in eliminating pollution in the area as well as maintaining reservoir pressure in this gigantic field, is an outstanding contribution to conservation to which the oil industry can point with pride.

Salt water disposal in West Texas, and particularly in the Permian Basin, has also been a problem of major concern to the industry from a pollution aspect. Because many of the oil fields in the area have solution gas drives and require secondary recovery mechanisms to obtain reasonable recoveries, waterflood operations received early and major emphasis throughout the area. The scarcity of suitable saline subsurface source water or even fresh water for such purposes in this semi-arid area has in most cases provided an urgent demand for all produced water, thereby creating a normal and useful subsurface disposal. In those instances, however, in which produced brines have not been used for flood purposes, the sandy and permeable character of the soil and need to preserve every available source of fresh water free from possible pollution have led to careful policing of pits by both operators and the Railroad Commission. In more recent months, with increasing emphasis on pollution control by both federal and state regulatory bodies, we have seen the passage of "no pit orders" by the Railroad Commission in essentially all West Texas counties. With the adoption of Statewide Rule 8, amended by Railroad Commission Order No. 20-56, 841, salt water disposal will become essentially 100 per cent subsurface by 1969.

The methods of treatment and the equipment used for salt water disposal and waterflood purposes are essentially alike. For secondary recovery a return on the investment is anticipated while disposal alone is usually considered a costly nuisance with no economic return, and is therefore often "poor boyed". Nevertheless, the disposal of oil field brine and other waste water to subsurface formations in a manner to assure freedom from pollution is an essential part of the lifting cost in our industry and is so recognized. With proper planning, design, and operation, a salt water disposal system may be operated for long terms at a minimum of cost.

The oil industry has been so successful in its use of this technique of waste disposal that it is being widely adopted by other industries and the Atomic Energy Commission for disposal of liquid wastes. Veir[1] recently described deep-well disposal practices of the Celanese Chemical Company at Bay City and Lockett[2] described similar practices of the petrochemical complex of El Paso Products Company of Odessa, Texas. You are all aware of the widespread publicity surrounding the disposal of chemical warfare arsenal wastes in Colorado. Deep-well disposal is being practiced in the states of Pennsylvania, Michigan, Indiana, Illinois, Iowa, Kansas, Oklahoma, Louisiana, Florida, Texas, New Mexico, Colorado, Arizona and California.

Details of planning, design, construction, testing, operation and economics of the salt water disposal system are covered thoroughly in the API Vocational Training Series, Book 3, Subsurface Salt Water Disposal[3]; Elliston[4,5] describes design features of surface equipment and Talbot[6] and Warner, Robeck and Hannah[7] describe in detail various factors in deep-well disposal systems. In view of the wealth of literature on the subject, the writer will confine the discussion primarily to newer developments in equipment being used in maintaining adequate water quality, and to corrosion control.

The assessment of adequate water quality is often most difficult. Wright[8] has provided tabular classification of water quality which is useful to the secondary recovery and disposal plant operator (Table I). The operator's objective should be to provide only sufficient treatment to render a water suitable for injection without decreasing injective capacity of the input well. Money spent in attaining a water of higher quality than this is money wasted. Of course anything less usually results in additional expenditures for well clean-out or stimulation, and is usually more expensive than the former in the end. Further work to more adequately define required water quality in individual situations is badly needed by the industry if optimum economy is to be achieved in this operation. Pressure build-up and fall-off tests as described by Morse and Ott[9] and Matthews and Russell[10] are helpful in determining adequacy of water quality.

TABLE I-A

WATERFLOOD RATING CHART

Rating	1	2	3	5	10	20
Membrane filter test (0.45 filter) slope	0-0.09 Excellent	0.10-00.29 Very Good	0.30-0.49 Good	0.50-0.99 Acceptable	1.00-1.79 Fair	1.80+ Excessive
Filtered solids mg/l	0-0.4 Negligible	0.5-0.9 Very low	1.0-2.4 Low	2.5-4.9 Moderate	5.0-9.9 Large	10.0+ Excessive
Total sulfide increases lb/day/1000 sq ft	0 None	0.001 Very low	0.002-4 Low	0.005-9 Moderate	0.01-0.019 Large	0.02+ Excessive
Iron-count increases lb/day/1000 sq ft	0 None	0.001-0.011 Very low	0.012-0.11 Low	0.12-0.59 Moderate	0.60-1.1 Large	1.2+ Excessive
Sulfate-reducing bacteria colonies/ml	0 None	1-5 Very low	6-9 Low	10-20 Moderate	30-90 Large	100+ Excessive
Total bacteria count colonies/ml	0 None	1-99 Very low	100-999 Low	1000-9999 Moderate	10,000-99,000 Large	100,000+ Excessive
Corrosion rate (30 days) (insulated coupon) mils/year	0 None	0.01-0.09 Very low	0.10-0.99 Low	1.00-4.9 Moderate	5.0-9.9 High	10.0+ Excessive
Pit depth (30 days) (insulated coupon) mils	0 None	1 Shallow	2-3 Minor	4-5 Moderate	6-10 Deep	10+ Excessive
Pit frequency (30 days) (insulated coupon) pits/sq in	0 None	1 Very low	2 Low	3 Moderate	4 High	5+ Excessive

TABLE I-B

INTERPRETATION OF RATING CHART

Rating Value	Rating	Philosophy
1	Excellent, negligible, or none	System in best possible condition with regard to this variable - the ideal.
2	Very good, very low, or shallow	System in very good condition with regard to this variable - less than ideal, but substantially better than a system in normal trouble-free operation.
3	Good, low, or minor	System in good condition - normal condition for trouble-free operation.
5	Acceptable or moderate	System in acceptable condition. However, condition is not as good as normal condition for trouble-free operation. System could be drifting towards trouble, hence the extra increase in the rating number.
10	Fair, large, high or deep	System in fair condition. System will be in serious trouble if these conditions continue to prevail. Hence, the heavy weighting of the rating number.
20	Excessive	System in trouble. These conditions will cause serious loss of injectivity or serious corrosion or both if continued. Hence, the extra heavy weighting of the rating number.

TABLE I-C

INTERPRETATION OF SULFATE REDUCING BACTERIA COUNT

Rating	Sulfate-reducing bacteria	Tube in which growth occurs
Excellent	0	None
Very Good	1 - 5	First Dilution Tube
Good	6 - 9	First Dilution Tube
Acceptable	10 - 20	Second Dilution Tube
Fair	30 - 90	Second Dilution Tube
Excessive	100 or more	Third Dilution Tube

TABLE I-D

INTERPRETATION OF TOTAL BACTERIAL COUNT

Total bacteria count

None	Perfect
1-99	A negligible number
100-999	Even a tenfold increase does not cause trouble
1000-9999	A tenfold increase is bordering on sufficient numbers to plug tight sands
10,000-99,000	A tenfold increase is sufficient to cause plugging of tight sands
100,000 +	Plugging of tight sands is occurring

SURFACE GATHERING AND INJECTION LINES

As revealed by available publications, a variety of piping materials are used in gathering and injection lines. Of these materials, probably asbestos-cement is most widely used in gathering systems and cement or plastic-lined steel in injection lines. More recently, a fiber glass reinforced plastic and polyvinyl chloride liner in steel have been introduced which have merit in some installations. The obvious purpose of all these nonferrous materials is to promote equipment life. Steel is very susceptible to corrosive attack in a salt water environment as will be discussed later. Ultimate decision must be made after investigation of pressures involved and comparative economics of the installed line.

OIL REMOVAL

Although the resolution of oil-water emulsions in a heater-treater, gun barrel, free water knock out, or other oil-water separation vessel at the tank battery has been widely practiced by the industry for many years, there are indications based on observed oil contents of water entering treatment plants that as effective a job of oil treatment is not being done as in the past. This possibly results from continuous rather than batch treatment attendant to LACT and from consequent reductions in personnel and added work-loading. Nevertheless, this added oil content of brine incoming to treatment plants creates additional processing problems in the plant including primarily heavier loads on the filters. If the problem is ignored there may be a plugging of the imput well. Every effort needs to be expended to assure very nearly complete oil-water separation at tank batteries by the use of effective demulsifiers, efficient operation of heat activated separation equipment and/or electrical dehydration equipment. Even so, effective baffling of water-receiving vessels at the water plant should be practiced to permit skimming of free oil to storage. Conventional coalescers, Fig. 1, are effective oil removal vessels when properly operated and coalescing media cleaned or replaced as needed. Without proper maintenance, however, such vessels may promote bacterial activity and provide an effluent of lower quality than that entering.

HORIZONTAL PRECIPITATOR AND OIL REMOVER

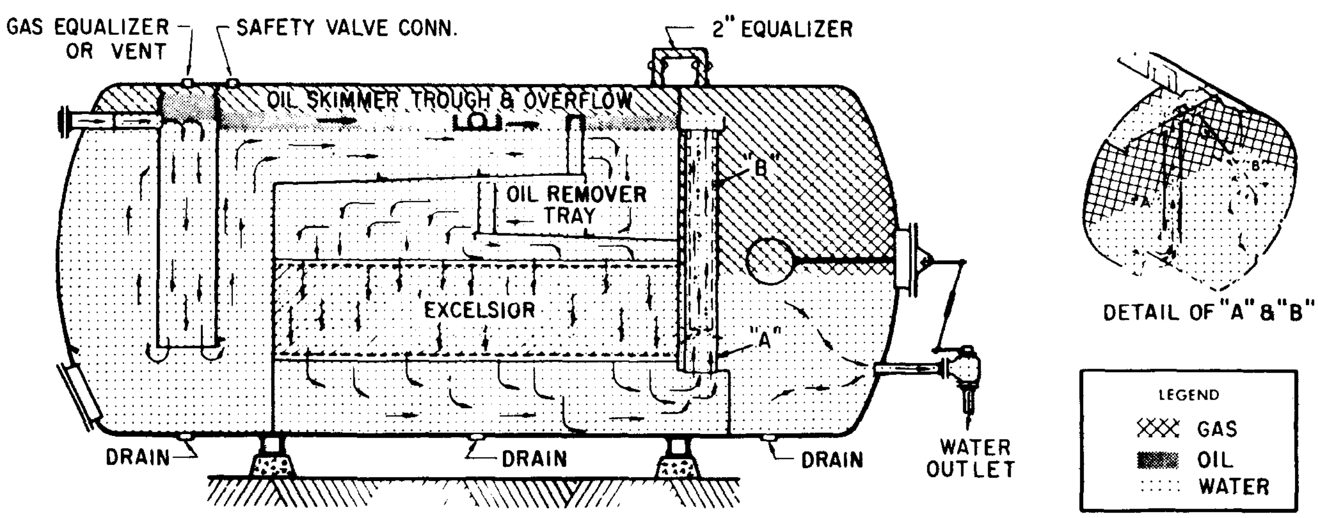


FIGURE 1

In areas handling sour brines the presence of traces of oil create serious problems in that the oil tends to wet suspended ferrous sulfide particles causing sufficient reduction in density of the particle to prevent its settling. The effective removal of these particles by means other than filtration is quite difficult and expensive. Although much work has been done in the development of surfactants and other exotic chemicals, an effective and economical solution to this problem is urgently needed.

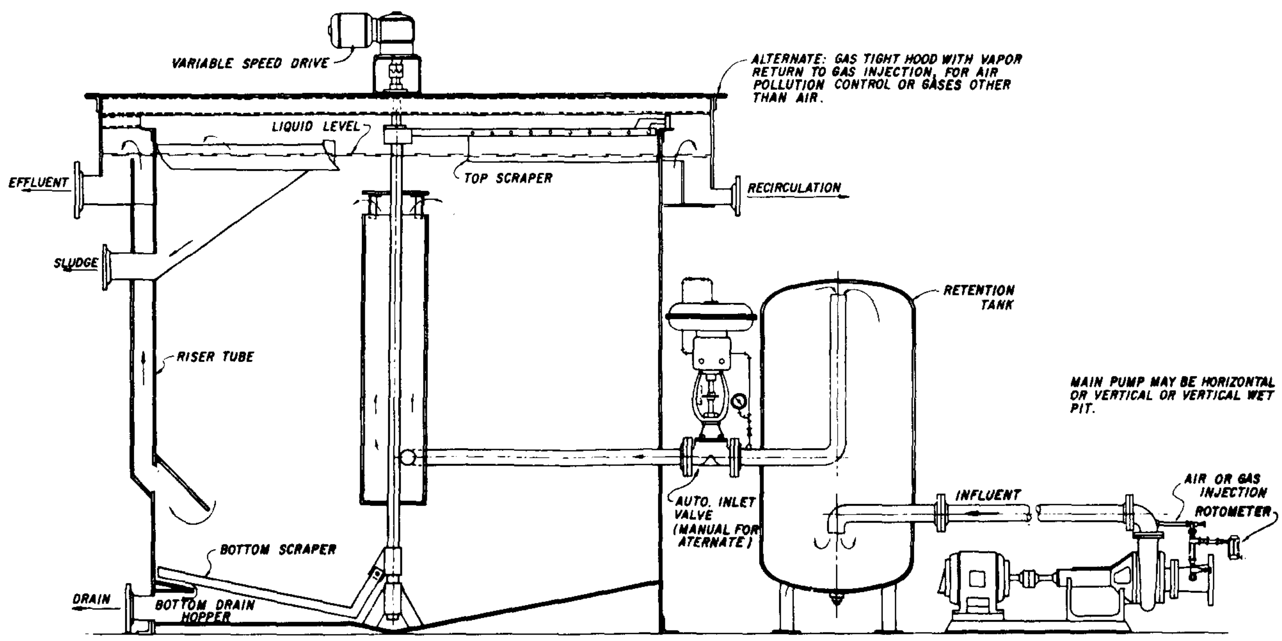
A more recent development in equipment to improve oil removal involves the use of a flotation cell, Fig. 2. This equipment, borrowed from the mining industry, has been used more widely in the California area and only to a very limited extent in this area. Field tests, however, indicate that when properly operated, an effluent of very low oil content is obtained. In some of the more difficultly resolved reverse emulsions (containing brines), the addition of various clays for proper coagulation and clarification may be required and the suspended solids content of the effluent may be increased.

FILTRATION

The filtration of salt water for subsurface disposal is described in thorough detail in prior references. Normally, filtration may not be required where disposal is into cavernous, vugular or fractured limestone or dolomite, but may be required if disposal is into sandstones.

Gravity or pressure-type filters using multigraded sand, crushed graphite or anthracite coal are widely used. Diatomaceous earth filters, although applicable to disposal operations, are more widely used in conditioning water for secondary recovery operations where high quality water is necessary. Such filters are capable of rendering a water of excellent quality, free of suspended solids and oil, when properly operated. However, closer surveillance is required in their operation without which an effluent of lower quality than that from the sand filter may be obtained.

In-line, expendable, cartridge-type or well head filters should be used for precautionary or secondary filtration only. If a brine contains enough suspended solids to require replacement of the cartridge more frequently than weekly or

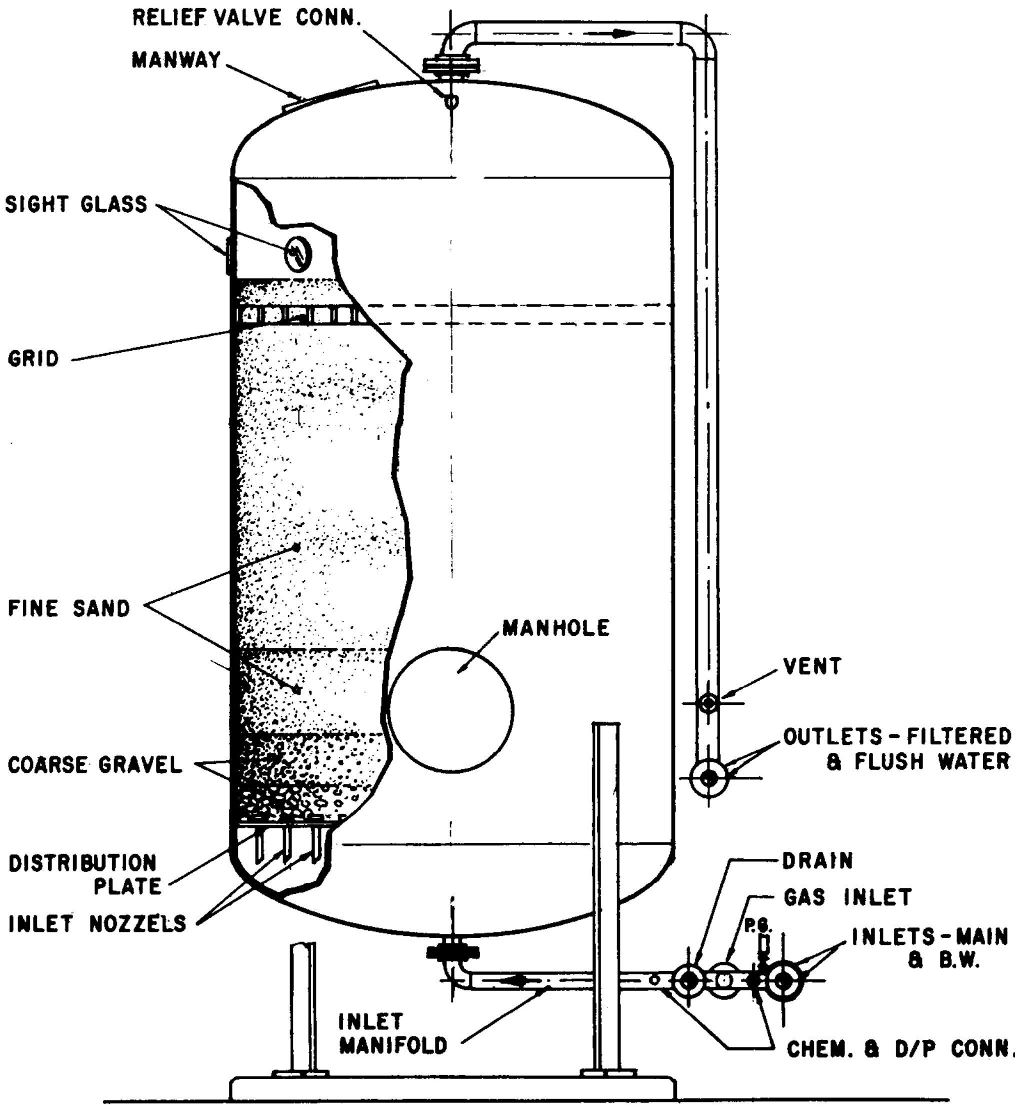


FLOTATION CELL

FIGURE 2

even bi-weekly, primary filtration is indicated and is probably more economical because of the excessive labor requirement.

A new type of filter recently introduced to the oil industry has shown improved results in removal of sediment and oil-wetted iron sulfide when compared with the more conventional filters. The unit, Fig. 3, is known as the Upflo filter and operates by flowing water upward through a thick, loose, graded-aggregate filter media. The grid located just below the sand top maintains a level surface and prevents washing the fine sand away during filtration. Filter backwashing is started by draining the water to the top of the sand bed and introducing compressed gas (or, less desirably, air) upward through the distribution plate to expand the media. With the bed thus in the expanded state, wash water is started in the same direction as filtration but at a higher flow rate. When wash flow is established, the gas flow is cut off and the bed permitted to continue washing for about 15 minutes.



UP-FLOW SAND FILTER

FIGURE 3

The bed is then allowed to settle and the sand surface is reformed by draining water to the top of the sand after which the filtration is begun.

The manufacturer recommends a filtration rate of 6 to 8 gal/min/sq ft of filter bed cross-sectional area. Gas flow to expand the bed should be maintained at about 5 cu ft/min/sq ft at 8 psig for 3 to 5 minutes. A back-wash flow rate of 15 gal/min/sq ft is recommended.

Field tests indicate the Upflo filter to be effective in removing finely divided iron sulfide (0.5 to 4.5 microns diameter) and oil-wetted iron sulfide at flow rates up to four times that of conventional pressure-type filters in similar service. The thick bed of filter media in the Upflo has a much greater sediment-holding capacity than does the surface of beds in conventional filters, thus permitting less frequent backwash. In general, it is not as efficient as a diatomaceous earth filter which is properly operated.

Backwash of such filters following a surfactant soak (or possible agitation by bubbling gas

OPEN OR RUN

CLOSE OR OFF

	FUNCTION										
	NORMAL	SIGHT GLASS DRAIN	INJ. CHEM.	BLOW GAS	SOAK	BLOW GAS	BACKWASH	WAIT	DRAIN	VENT	RE-SET TO NORMAL
TIME-MIN.		1	5		30	5	15	5	5	1	
A SOURCE WTR. VALVE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN
B CHEMICAL PUMP	CLOSE	CLOSE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
C BACKWASH PUMP	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE
D BACKWASH VALVE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE
E EFFLUENT VALVE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN
F GAS VENT VALVE	CLOSE	CLOSE	OPEN	OPEN	OPEN	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE
G BACKWASH STG. VALVE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN	CLOSE	OPEN	CLOSE	CLOSE
H DRAIN VALVE	CLOSE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN	CLOSE	CLOSE
I BLOWCASE VALVE	CLOSE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN	CLOSE	CLOSE
J GAS SUPPLY VALVE	CLOSE	CLOSE	CLOSE	OPEN	CLOSE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
K PRODUCED WTR. VALVE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN
L B.W. WTR. SALVAGE PMP.	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN

AUTOMATIC SEQUENCE SCHEDULE

FIGURE 4

slowly up through the bed) has been very effective in restoring oil-soaked filter media.

Such filters as well as all filters may be readily automated by pressure drop or time-cycle activation. Figure 4 shows typical automation sequence schedule for an Upflo filter.

CONTROL OF BACTERIA

The adverse effect of bacterial activity on injective capacity of input wells in secondary recovery as well as disposal operations has been well recognized for some time. The assessment of the extent of such activity and its effect on injective capacity as well as its influence on corrosion of subsurface equipment has been the subject of a number of papers.[11,12]

Bacteria of the general classification of aerobes, anaerobes and sulfate-reducers are generally implicated in production operations. Aerobes thrive most readily in the presence of dissolved oxygen originating from contact with air and can, in most cases, adapt to anaerobic (oxygen-free) conditions also. Such bacteria often cause plugging of filters and injection sands and contribute to slime formation in lines and pumping equipment. Some produce hydrogen sulfide if the water contains much organic matter.

Sulfate-reducing bacteria, the most widely publicized, are anaerobic and are involved in the production of hydrogen sulfide which leads to corrosion and possible plugging of formations. Anaerobes, other than sulfate reducers, have been reported to be responsible for some corrosion, but unless present in extreme numbers, are considered the least important.

Definite limits cannot be set at which bacterial activity becomes excessive. Each system must be evaluated separately considering such factors as (1) the salinity of the water involved, (2) its organic matter content, (3) the type and permeability of the input formation, (4) the type, kind and location of filters, (5) the physical treatment of the water and (6) its retention time in the system. Frequently, aerobes or slime-formers may be greatly reduced or completely eliminated by (1) the elimination of exposure of water to air or (2) the removal of dissolved oxygen (to be discussed later). The advice of a qualified water-treating or chemical engineer should be sought here.

Bactericides which are widely used to control bacterial activity usually fall into one of the following six types:

(1) Chlorine
(2) Formaldehyde, other aldehydes
(3) Quaternary ammonium compounds
(4) Amines and diamines
(5) Chlorinated phenols
(6) Organic sulfur compounds

The advantages and disadvantages of these compounds are shown in Table II. Chlorine is probably the most economical and widely used compound in municipal water treating. Special feed equipment is required, and chlorine is highly irritating to the respiratory tract. Amines and diamines are more widely used in salt water disposal and waterflood work because they are, in the absence of oxygen, effective corrosion inhibitors as well.

CONTROL OF CORROSION

The extent to which corrosion is controlled in salt water disposal or waterflood operations will determine if an economically successful operation is to result. The technology of corrosion control has improved remarkably in recent years and if a control program is properly designed for the environmental conditions and rigorously carried out, acceptable corrosion rates should be achieved.

Unaerated oil field brines, in the absence of excessive concentrations of acid gases such as hydrogen sulfide and carbon dioxide, are not significantly more corrosive than sea water. Although difficult to generalize, corrosion rates of 5 mils per year and less are common. However, in the presence of hydrogen sulfide and carbon dioxide, corrosion rates accelerate rapidly and, if oxygen is present, the corrosion rate may become excessive. Frequently, if oxygen is present, early corrosion failure of ferrous material occurs because of the pitting-type attack characteristic of such brines. This may be true even if coupon rates are low since such rates represent overall surface area effects rather than localized pitting effects. Cases have been observed in which corrosion perforation of schedule 40 line pipe occurred in less than six months although corrosion coupon rates of 1 to 3 mpy were recorded.

TABLE II

COMPARISON OF VARIOUS TYPES OF COMMERCIAL BACTERICIDES

Bactericide Type	Advantages	Disadvantages
I. Chlorine	1. Cheap on a pound-cost basis 2. Widely available 3. Effective against a wide range of microorganisms	1. Highly toxic and requires special equipment for safe handling and use 2. Residual chlorine required for effectiveness. Chlorine must react fully in system to obtain a free residual 3. Can cause corrosion problems 4. Can oxidize ferrous iron to ferric state and cause plugging problems
II. Formaldehyde, Other Aldehydes	1. Cheap on a pound-cost basis 2. More easily handled than chlorine 3. Initially effective against most microorganisms	1. Microorganisms often quickly adapt to presence of formaldehyde, and product loses effectiveness 2. Difficult to handle; causes skin irritation and vapor is irritating to nose and eyes. 3. Treating costs are often high
III. Quaternary Ammonium Compounds	1. Effective bactericides and fungicides in proper environment 2. Easily handled liquid products 3. Good corrosion inhibitors 4. Relatively non-toxic 5. Good detergents	1. Treating costs are often high compared to other products 2. Ineffective in water containing much over 1000 ppm total solids. Use is generally restricted to fresh water systems
IV. Amines and Diamines	1. Effective bactericides and fungicides in fresh and brine waters 2. Effective corrosion inhibitors 3. Generally the lowest cost on a per-gallon basis of the multiple function products 4. Conveniently handled liquid products	1. Less effective on a treating cost basis in high brine waters than certain products 2. Products become less effective after prolonged use or in dirty systems. May be associated with oil solubility and cationic nature of product. Bacteria may develop immunity. 3. There are reports of formation plugging from diamines, particularly in high brine waters 4. Will cause skin irritation
V. Chlorinated Phenols (In combination products)	1. Generally found to be the most effective bactericides on a treating cost basis in high brine systems 2. Effective corrosion inhibitors when used in combination products 3. Mechanism of kill allows slug treating at lower cost than continuous treating	1. If crude contamination occurs, products can cause corrosion problems in refineries from breakdown of chlorinated phenols under heat 2. Products are higher cost on a per-gallon basis than the diamines 3. Products are toxic and can cause skin and eye damage 4. Products will contaminate fresh water systems in high concentrations. They are safe at normal treating rates. 5. Products are oil soluble, and lose effectiveness if emulsified oil in water is present.
VI. Organic Sulfurs	1. Effective bactericides at low treating costs 2. Product is equally applicable in fresh and high brine waters 3. Product is water soluble and oil insoluble. Does not absorb on filters 4. Low toxicity to warmblooded animals 5. Conveniently handled liquid products	1. Products cannot be tested by present laboratory screening methods. Difficult to justify field tests without lab data. 2. Products require continuous treatment because of mechanism of action. This is sometimes difficult in oil patch 3. Products have no corrosion inhibiting properties as such 4. Products require stainless steel equipment because of high pH 5. Products may not be mixed with cation corrosion inhibitors in concentrated form because of high pH. Compatible in system

Organic corrosion inhibitors, primarily of the amine, diamine or imidazoline types, are frequently very effective in reducing corrosion rates to acceptable levels if oxygen is absent. Such inhibitors have very limited inhibition capacity in the presence of oxygen and if significant concentrations of hydrogen sulfide are present, a detergent is essential to the composition of the inhibitor. Otherwise, adhering iron sulfide will set up localized concentration cells causing severe localized pitting.

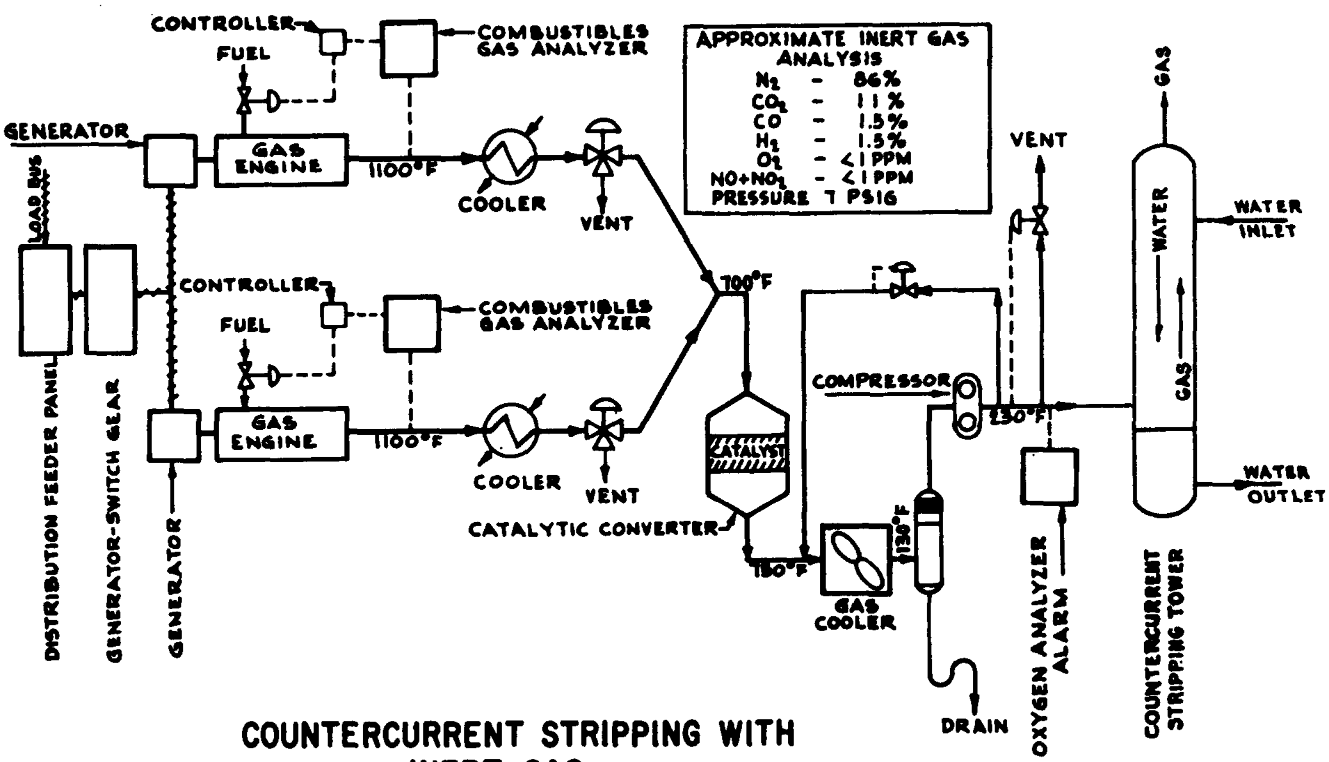
The presence of oxygen in any concentration causes serious corrosion and particularly so if hydrogen sulfide is present simultaneously. It is for this reason that the maintenance of closed systems (i.e., "gas blanketing") is so strongly emphasized. The maintenance of a 2-ounce positive pressure natural gas "blanket" on all brine-handling vessels is highly effective in eliminating exposure of the water to air and thereby greatly reducing corrosion of contacted metals.

If hydrogen sulfide is present, corrosion may be controlled by the use of organic inhibitors containing detergents to disperse precipitated iron sulfide, or, in severe cases, by countercurrent stripping of the water with inert or natural gas to remove the hydrogen sulfide. Frank describes such an operation in a paper to be presented to the Petroleum Division of the American Society of Mechanical Engineers. Humble operates such units at Pembrook and Wickett, Figs. 5 and 6.

If oxygen is present, it may be removed by one of the following methods:

(1) Chemical reaction
  (a) Sodium sulfite
  (b) Hydrazine
  (c) Sulfur dioxide: liquid; sulfur burner
(2) Vacuum deaeration
(3) Countercurrent stripping
  (a) Natural gas
  (b) Inert gas

Chemical scavenging using sodium sulfite is estimated to cost about 2 mils per barrel for removal of 9 ppm oxygen (saturation concentra-



COUNTERCURRENT STRIPPING WITH INERT GAS SCHEMATIC OF PEMBROOK

FIGURE 5

tion varies with salinity and temperature) while hydrazine is appreciably more expensive. Liquefied sulfur dioxide is available under contract arrangements for similar applications at a cost of about 1 mil per barrel in large volume installations. Perry and Frank[13] described the generation of sulfur dioxide by the burning of sulfur at a somewhat lesser cost (see Fig. 7). The latter method is not without operational problems, however.

Adams[14] reports the use of vacuum deaeration for the reduction of oxygen to a level of 0.5 to 0.8 ppm in water at the Northwest Witcher Unit in Oklahoma. He reports an operating cost of $2.40 per day in handling 20,000 barrels of water (0.12 mil per barrel) and an investment of $9300. Further chemical scavenging to 0.05 ppm would increase this cost to about 0.30 mil per barrel, (Fig. 8).

Weeter[15] reports the use of countercurrent stripping with natural gas for the removal of oxygen from water at SACROC to less than 0.05 ppm at a cost of about 0.10 mil per barrel. If the stripping gas may be used for engine fuel without recompression, the cost of operation should be even less, (Fig. 9).

SUMMARY

With few exceptions, the oil industry has accepted subsurface disposal of oil field brines

PROCESS FOR REMOVAL OF
HYDROGEN SULFIDE FROM WATER

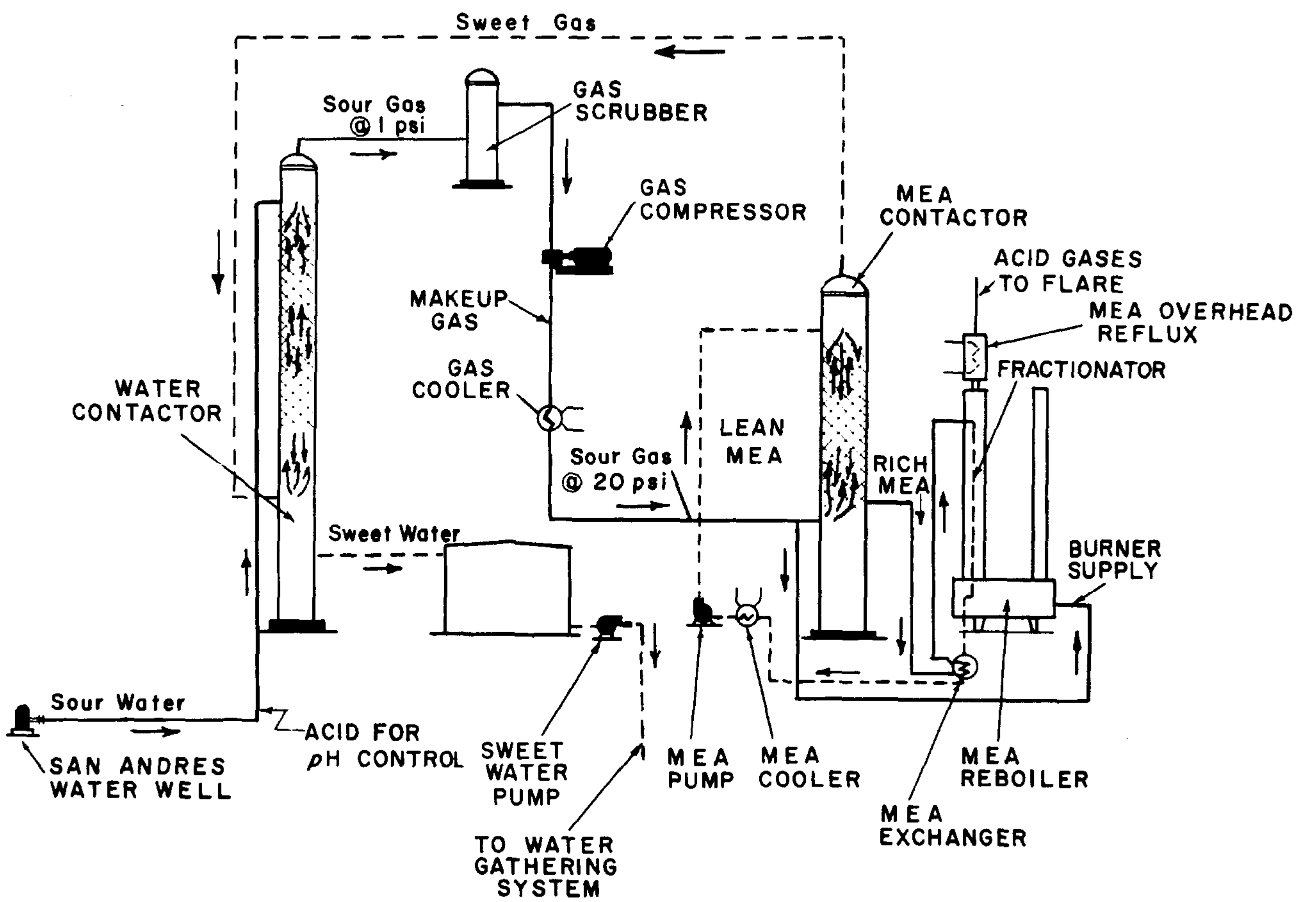


FIGURE 6

as the method least likely to create pollution problems. It is constantly seeking improvements in the associated technology and equipment and means of achieving further economy in its application.

Significant progress has been made in recent years in the development of improved protective coatings, plastic pipe, organic inhibitors, and bactericides, all designed to provide longer, corrosion-free service of surface and subsurface equipment.

Although some improvement has been noted in oil removal equipment and chemical demulsifiers and surfactants, further work is needed in this and related areas to provide solutions to excessive oil contamination and oil-wetted iron sulfide problems. The flotation clarifier appears to offer considerable promise of an early solution to this troublesome problem.

Work is also needed to more clearly define required water quality for specific formation characteristics.

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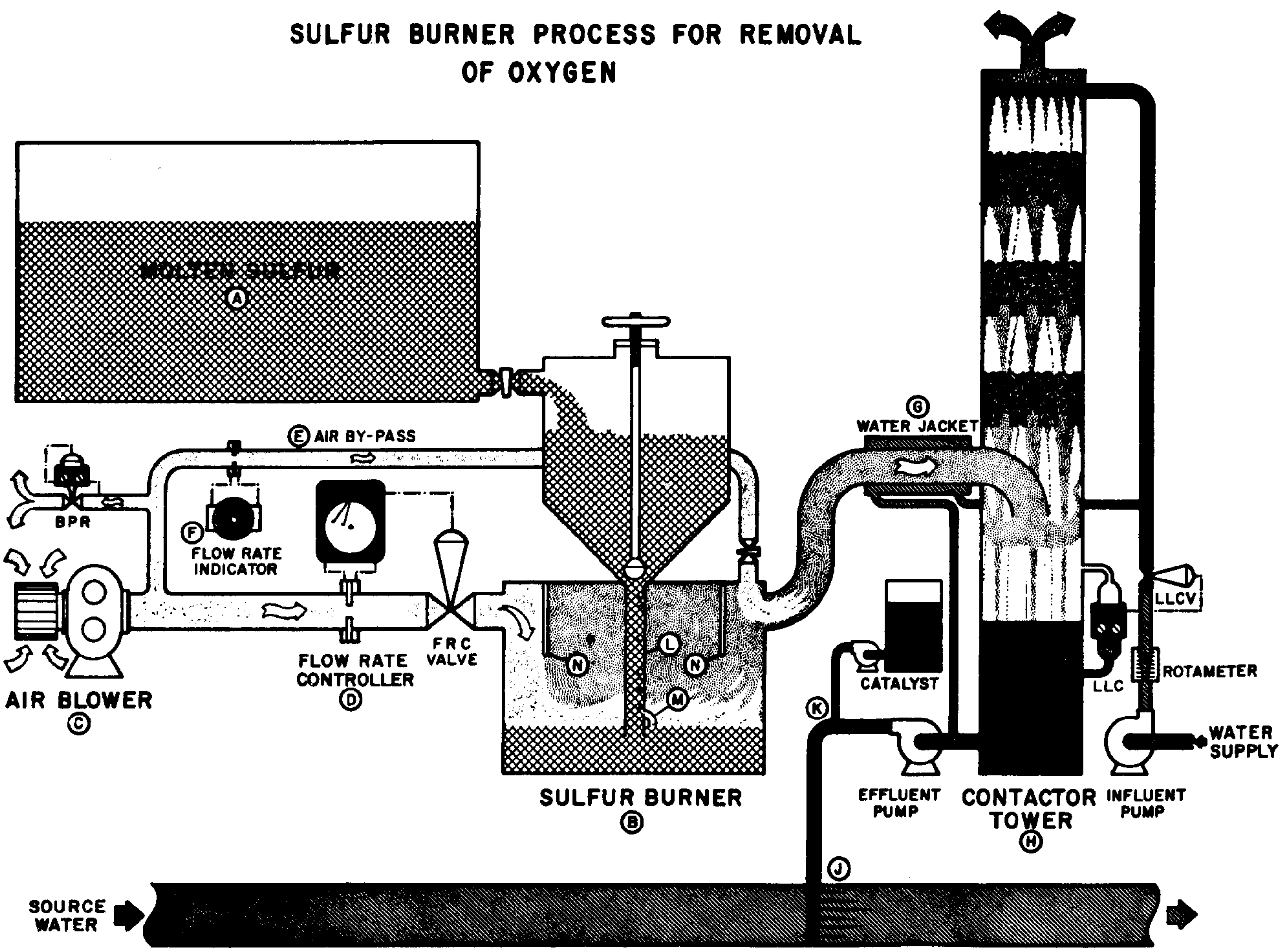

FIGURE 7

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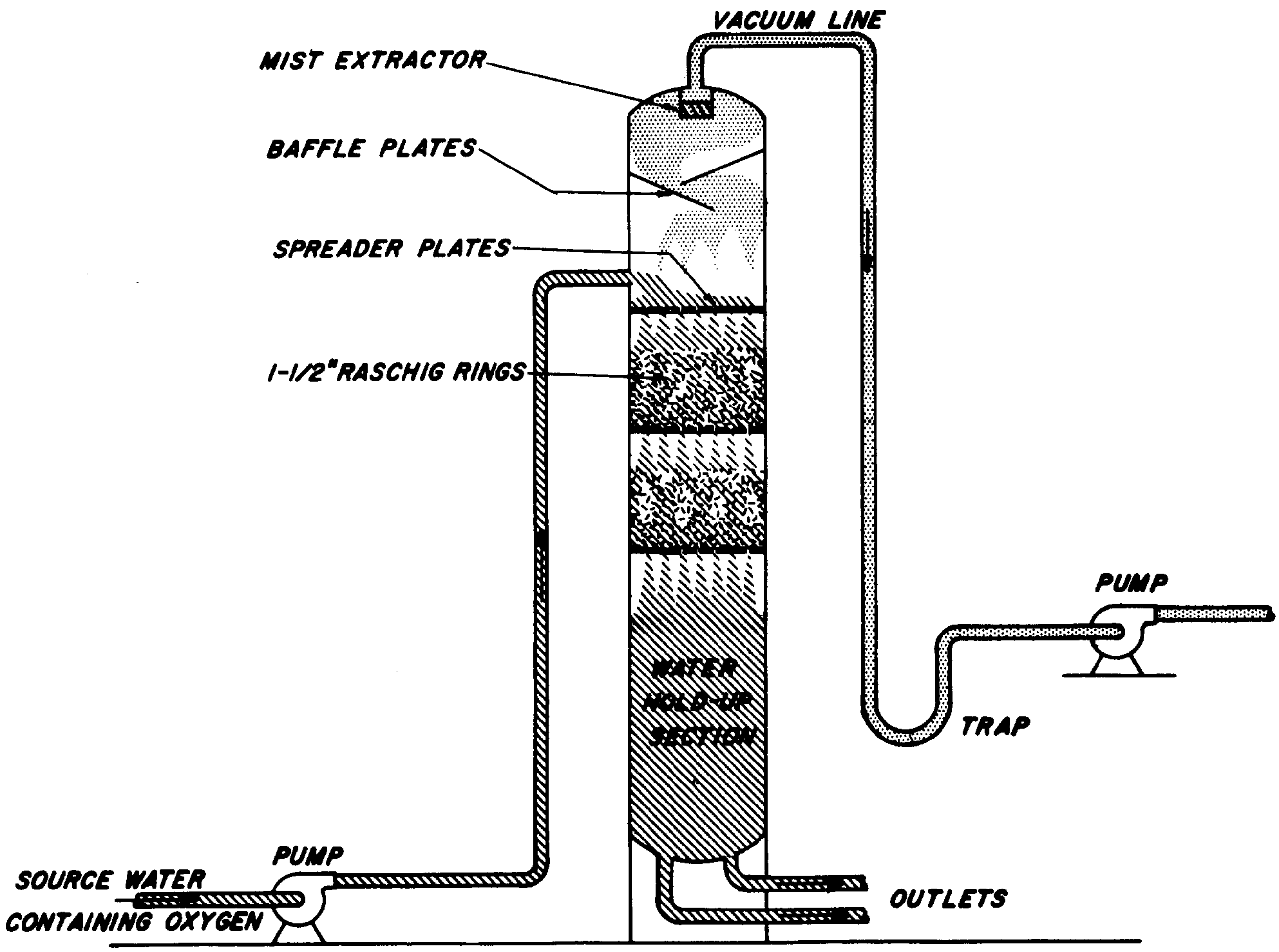
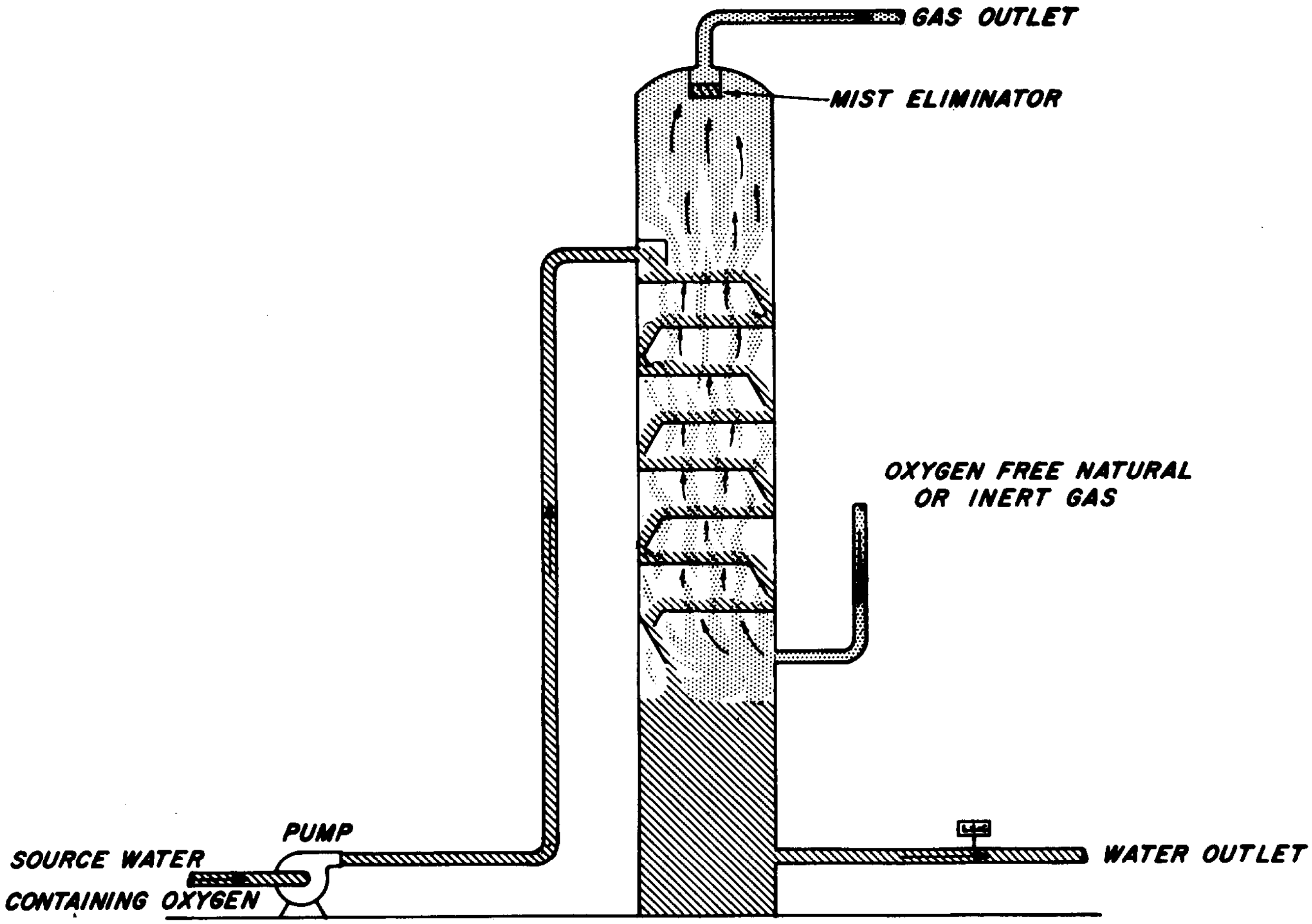


VACUUM DEAERATOR

FIGURE 8



COUNTERCURRENT STRIPPING TOWER

FIGURE 9

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