GAS PRODUCTION DURING REFUSE DECOMPOSITION

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Abstract. Gas production in sanitary landfills is a subject of much concern because of the potential hazards of CH_4 combustion and of groundwater contamination by CO_2. This study investigated the pattern of sanitary landfill gas production and the factors which affect it.

A basis for study was prepared by examining factors which influence gas production in soil and sewage sludge digesters. The factors studied included moisture content, temperature, pH, alkalinity, Eh, and nutrition. It was then undertaken to determine whether or not this information was applicable to the landfill.

A pattern for landfill gas production was proposed based on the assumption that an anaerobic environment would be achieved and maintained after refuse placement. Four phases were identified: I. Aerobic; II. Anaerobic Non-Methanogenic; III. Anaerobic Methanogenic Unsteady; and IV. Anaerobic Methanogenic Steady. The duration of these phase and the relative amounts of gases produced within each phase were studied.

An investigation of information available on factors affecting gas production in sanitary landfills also was made. It was found that, in general, the principles developed from the study of gas production in other media were applicable to the landfill environment. It was found that gas production increases with increased moisture content but that conditions of high infiltration are often conducive to reduction in gas production apparently caused by modifications to the microbial environment. There appears to exist a typical pattern of temperature variation within the landfill with a peak temperature being reached during the initial phase of aerobic decomposition. The magnitude of this peak is related to the refuse temperature at placement. Subsequent temperatures are lower and tend to fluctuate with season. Optimum temperatures for gas production are in the range of from 30 °C to 35 °C, however, landfill temperatures are often lower than this. Optimum levels of pH and alkalinity exist which maximize gas production rates. The types and amounts of gas produced are influenced by refuse composition.

A scheme was proposed to illustrate how the various factors influence landfill gas production and how these may interact. Those factors over which some control may be exerted during landfill design and operation were identified.

Notations

BOD biochemical oxygen demand, mg l^{-1}.
COD chemical oxygen demand, mg l^{-1}.
Eh oxidation-reduction potential, millivolts.
mV millivolts.
VDS volatile dissolved solids, mg l^{-1}.

1. Introduction

Gas production in sanitary landfills and the problems associated with this production, in particular the explosion potential due to the combustibility of CH_4 and the acidification of groundwater due to the solution of CO_2, have come to represent an area of active concern in the disposal of solid wastes (Kellow, 1972). The mechanism of gas production in landfills and the factors which affect it have not, however, been brought to light. This study was, therefore, undertaken to evaluate available information in order that landfill gas production and its attendant problems might be better understood.

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2. Gas Production in Other Media

Data specific to the landfill were sparse. However, it was assumed that gas production, arising from the biological decomposition of organic material, has much which is constant, regardless of the context in which the decomposition occurs. Since much information about the decomposition of sewage sludges and the destruction of organic material in soil was available, it was decided to use it as a basis for investigating gas production in sanitary landfills.

Anaerobic decomposition was studied in order to focus on the production of CH_4. The term 'anaerobic decomposition' was taken to mean the attack of a mixed microbiological culture on complex organic material in the absence of O_2. The attack was assumed to consist of a non-methanogenic stage and a methanogenic stage, the features of which are described below (Toerien and Hattingh, 1969).

2.1. The non-methanogenic stage

Hydrolytic processes initiate the non-methanogenic stage by reducing complex organic matter to smaller, soluble components by means of extra cellular enzymes (McCarty, 1963; Imshenetsky, 1968; Kotze *et al.*, 1969; Toerien and Hattingh, 1969). Products of hydrolysis include fatty acids, simple sugars, amino acids and other low molecular weight organic compounds. The microorganisms expend more energy than is immediately recovered during hydrolysis. However, the organic material is modified for use in subsequent energy yielding reactions. Hydrolysis is not likely to be a rate limiting step in decomposition (Toerien and Hattingh, 1969).

Additional activities within the non-methanogenic stage accomplish further modification of the organic material with the capture of energy and the formations of organic acids, ammonia, water and the production of the gases H_2 and CO_2. Controversy exists over the types and relative amounts of organic acids produced during this stage but most investigators identify CH_3COOH as a dominant product (McCarty, 1963; Kotze *et al.*, 1969; Toerien and Hattingh, 1969). Controversy exists as well about the microbial flora, whether they are facultative or strictly anaerobic and a concensus does not appear to exist. One aspect appears well established, however, and that is the microorganisms of this stage are far more tolerant and far less fastidious than those of the methanogenic stage, the methane forming bacteria (Toerien and Hattingh, 1969).

2.2. The methanogenic stage

The microorganisms active in the methanogenic stage are generally considered to be bacteria of the negus *Methanobacterium* common inhabitants of soil and sewage (Toerien and Hattingh, 1969; Alexander, 1971). They obtain energy from two reactions, from the reduction of CO_2 through the addition of H_2 to form CH_4 and H_2O, and from the cleavage of CH_3COOH into CH_4 and CO_2. McCarty (1963) reported that while energy is captured by the microorganisms during this stage, very little synthesis of new cell material occurs.

The gases N_2 and H_2S may also be produced during anaerobic decomposition.

Nitrogen is produced from the microbial process of denitrification in which the nitrate ion is reduced while acting as a terminal electron acceptor. Denitrification occurs immediately upon the depletion of O_2 (Alexander, 1971). Hydrogen sulphide is produced by sulphate reducing microorganisms with a sulphate ion acting as well as a terminal acceptor. The reaction proceeds at neutral or slightly alkaline pH (Alexander, 1971).

The production of other gases such as CH_3CH_3, $CH_3CH_2CH_3$, and PH_3 is considered to be negligible (McCarty, 1963; Skinner, 1968).

Thus, during the anaerobic decomposition of organic material, the potential exists for the production of the gases CO_2, H_2, CH_4, N_2, and H_2S. Hydrogen is produced during the non-methanogenic stage but consumed during the methanogenic stage. Toerien and Hattingh (1969) reported that the latter reaction proceeds at a much more rapid rate than the former and, therefore, H_2 is geneially not found in the presence of CH_4. Ammonia may be produced in the gaseous from under conditions of alkaline pH.

2.3. Environmental factors affecting gas production

While the production of CH_4 is a common process in natuie, it is at the same time a delicate one, having rather specific environmental requirements which render the methanogenic stage perhaps the most easily disturbed of the anaerobic processes. The major environmental factors which affect the production of CH_4 are summarized below.

Moisture is required for the activity of most microorganisms including the CH_4 bacteria and it is likely that this activity increases with moisture content. Methane bacteria perform well in digesters where the moisture content is generally in excess of 90% of the wet sludge weight. Skinner (1968) reported that the water-logging of soils increased gas production including that of CH_4.

The optimal pH range for CH_4 production during sewage sludge digestion was reported to be 6.4 to 7.2 by Kotze *et al.* (1969), while Skinner (1968) defined a tolerant range in soil of from 5.5 to 9.0. McCarty (1963) stated that CH_4 production was possible in acid bogs but gave no range of tolerable pH.

Bicarbonate alkalinity in excess of 2000 mg l^{-1} expressed as calcium carbonate and ammonium ion in excess of 100 mg l^{-1} expressed as NH_3 were considered to be necessary by Kotze *et al.* 1969) for maximum CH_4 production. They also defined a maximum allowable organic acids concentration of 3000 mg l^{-1} as CH_3COOH with much lower concentrations being preferable.

Methane production also requires that the oxidation-reduction potential (Eh) of the environment be well into the negative range, generally less than 200 mV. This is true for decomposition in both soil (Imshenetsky, 1968; Skinner, 1968; Alexander, 1971) and in anaerobic digestors treating sewage sludges (McCarty, 1963; Toerien and Hattingh, 1969).

Anaerobic decomposition has been found to proceed within three temperature ranges: the thermophilic range with temperatures greater than 44 °C, the mesophilic range with temperatures between 20 and 44 °C and the psychrophilic range with temperatures less than 20 °C (Kotze *et al.*, 1969). The general trend is toward increasing rates of decomposition and thus gas production increases with temperature up to 55 °C beyond which decompositions rates decline sharply. Methane production is sensitive to abrupt changes in temperature and may be disturbed by changes as small as 1 to 2 °C (Kotze *et al.*, 1969).

Skinner (1968) reported no impedance to CH_4 production at gauge pressures up to 35 psi.

While its extent is limited, some knowledge of the nutritional requirements for maximum gas production during anaerobic decomposition exists. For example, Kotze *et al.* (1969) described an optimal C to N ratio of 16:1. McCarty (1963) recommended minimum concentrations of metallic ions, in particular, a minimum of 20 mg l^{-1} of ferrous iron. Notwithstanding that the data are limited, it can be stated that variations in nutrition will affect the rates of decomposition and gas production and the types of products formed.

Thus, with many of the environmental factors affecting CH_4 production in soil and sewage sludge digesters having been identified, it was decided to investigate their application to the sanitary landfill.

3. A Pattern for Sanitary Landfill Gas Production

A pattern assumed to be typical and describing the sequence of events during gas production in a landfill is presented in Figure 1. Its development was based on the assumptions that, upon placement, subsequent aeration of the refuse does not occur and that conditions within the decomposing refuse are sufficient to encourage and to sustain CH_4 production.

Four phases are identified and designated as Phase I Aerobic; Phase II. Anaerobic Non-Methanogenic; Phase III. Anaerobic Methanogenic Unsteady and Phase IV. Anaerobic Methanogenic Steady.

In Phase I, aerobic decomposition takes place with the consumption of oxygen present in the refuse at the time of placement. Carbon dioxide is produced in approximate molar equivalents to the O_2 consumed (Ludwig, 1961). Very little displacement of N_2 occurs.

Upon the depletion of O_2, the gas production pattern enters Phase II where anaerobic activity becomes dominant. During this period a CO_2 bloom, a peak in CO_2 concentration, occurs and H_2 production is in evidence. Displacement of N_2 occurs, however, and some N_2 production via denitrification may exist. Methane production has not yet begun. The lag in CH_4 production after anaerobiosis has been achieved may be due to the need for adequate amounts of CO_2 in solution to act as a H_2 acceptor (McCarty, 1963).

Ludwig (1967) observed peaks in CO_2 concentration at two California sanitary landfill sites. After 11 days, 70% by volume CO_2 was measured at the Azusa site while 50% by volume was observed at the Calabasas site after 23 days. Beluche (1968) observed a peak CO_2 concentration of 90% after 40 days during a sanitary landfill test cell study. Phase II H_2 concentrations in the order of 20% by volume were observed by Lin (1966), Ramaswamy (1970), and Songonuga (1970).

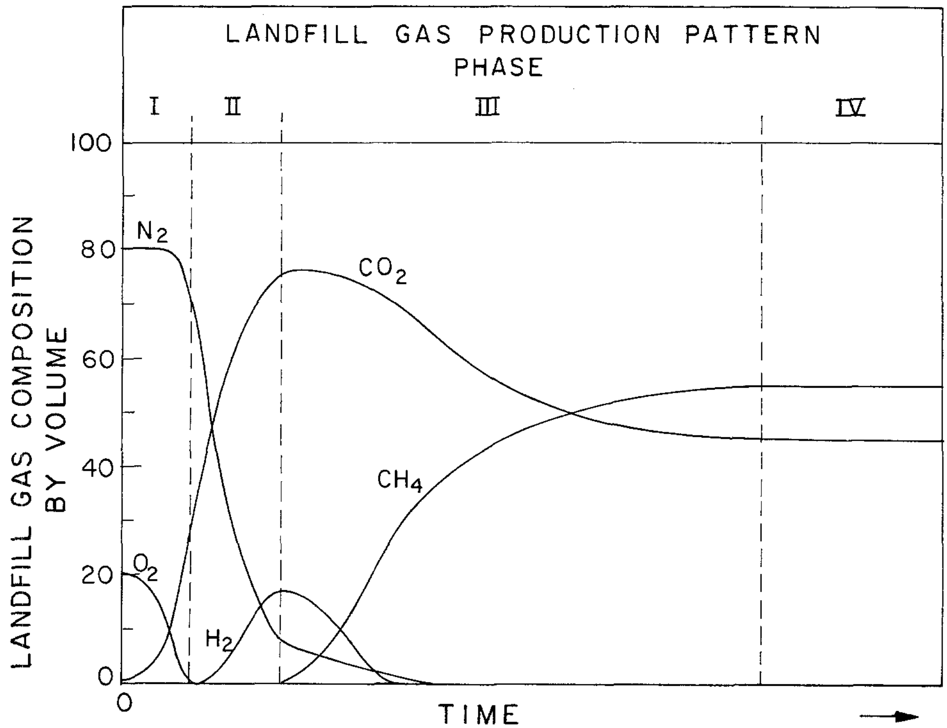

Fig. 1. Sanitary landfill gas production pattern.

The term unsteady is used to describe Phase III because here the concentration of CH_4 increases to some relatively constant terminal value. Hydrogen disappears in the initial portion of this Phase since the *Methanobacterium* appears capable of using it at a very rapid rate (Toerien and Hattingh, 1969). Both CO_2 and N_2 concentrations reduce to some terminal concentrations.

Data from Ramaswamy (1970) suggest a completion time for Phases I, II and III of approximately 180 days. The work of Rovers and Farquhar (1972) shows a corresponding time of 250 days while 500 days appears to have been required in the studies of Beluche (1968). In all these cases, experimentation was conducted with cylinders filled with refuse to simulate a landfill and it may be, therefore, that the results are atypical of actual landfill conditions.

During Phase IV the composition of the gases produced and the rates of production remain steady at their peak for the prevailing conditions. This does not preclude the occurrence of abrupt variations in gas production due to changes in environmental conditions nor does it account for long-term variations caused by such things as nutrient depletion or the accumulation of inhibitory materials. Landfill gas compositions of from 50 to 70% CH_4 and from 30 to 50% CO_2 can be expected in this Phase (Dunn, 1960; Bevan, 1967; Beluche, 1968; Ramaswamy, 1970). This corresponds well with data published by Kotze *et al.* (1969), which gives a gas composition of 66% CH_4 and 34% CO_2 for gases produced during the digestion of sewage sludges. Small amounts of N_2 and H_2S may also be present.

If the concentration of CH_4 is substantially less than 50% by volume, it is likely that its production is being retarded, particularly if H_2 is detected (Kotze *et al.*, 1969). Abrupt changes in gas composition usually reflect some change in environmental conditions.

The pattern described here is typical. However, it is understood that the duration of any one phase and the relative amounts of the gases produced within it will vary as conditions change from one landfill to the next.

4. Some Observations at the Landfill

Many of the factors influencing gas production in other media have been established. It was assumed that these could be applied to the sanitary landfill environment and there is evidence that this assumption may be valid.

4.1. Moisture content

Ramaswamy (1970) and Songonuga (1970) found that gas production rates increased with increased refuse moisture content with maximum production occurring at moisture contents from 60% to 80% wet weight. The percentage of CH_4 in the gases produced also increased with increased moisture content. Rovers and Farquhar (1972) observed that the moisture content of refuse as collected, ranged from 5% to 50% by weight. If the results of Ramaswamy (1970) and Songonuga (1970) are taken as typical, then refuse as placed in sanitary landfills may contain insufficient moisture for maximum gas production notwithstanding that some gas production may occur regardless of the moisture content.

Ludwig (1967) found that gas concentrations increased in the Azusa landfill site after a heavy rainfall. Merz and Stone (1969) found that refuse placed at a moisture content ranging from 30% to 40% wet weight developed an initial CO_2 bloom after which gas production stopped. The addition of moisture was required to maintain subsequent gas production. It may be that moisture contents insufficient to support maximum gas production rates are common in sanitary landfills.

4.2. Excessive infiltration

Rovers and Farquhar (1972) studied gas and leachate production in refuse placed in a 400 cubic foot (11.32 m^3) cylindrical test cell. Phase II gas production began 20 days after placement and leachate release from the refuse first occurred after 35 days. After 115 days, gas production has entered Phase III and a CH_4 concentration of 19% by volume had been achieved. At that point, large amounts of water generated from melting snow and ice infiltrated the refuse causing a large increase in leachate production. The infiltration coincided with a reduction in CH_4 gas concentration to 4% by volume and with the following changes in leachate characteristics: chemical (COD) and biochemical oxygen demand (BOD) and volatile dissolved solids (VDS) concentrations increased while alkalinity and pH decreased.

It was concluded that these events had taken place because of an inhibition of the CH_4-forming bacteria. This would increase the organic acids concentration thus increasing the concentrations of COD, BOD and VDS and decreasing alkalinity and pH. The cause of the inhibition is not known. The large volume of infiltration water resulted in a slight reduction in refuse temperature less than 3 °C. Kotze *et al.* (1969) stated that temperature changes of 1 to 2 °C were sufficient to interfere with CH_4 production. He did not indicate to what extent this might occur. It was felt, however, that other factors had been involved, particularly since subsequent similar events were observed to coincide with large amounts of infiltration without a change in refuse temperature.

Because of equipment difficulties, Rovers and Farquhar (1972) were unable to obtain measurements of Eh in their experiments. It has been shown that, in other media, optimal conditions for CH_4 production include an Eh of less than -200 mV. Golwer *et al.* (1971) measured the Eh of groundwater infiltrating sanitary landfills to be, on occasion, in excess of ± 380 mV. The infiltrating water of the Rovers and Farquhar (1972) study was likely to have been well into the positive range. This would have increased the Eh in the environment of the CH_4 forming bacteria thus inhibiting their activity. Although no O_2 or decreased CO_2 concentrations were observed, aeration of of the refuse from air drawn in by the infiltrating water may also have occurred. This too could disrupt CH_4 production.

In a second experiment, performed by Rovers and Farquhar (1972), a 95 cubic foot (2.69 m^3) cylindrical test cell was filled with compacted refuse, sealed and supplied with water intermittently at a rate of approximately 6 cm mo^{-1} for a period of 200 days. This was done to investigate conditions of extreme infiltration. Large amounts of CO_2 were produced but CH_4 production was absent. The pH of the leachate remained near 6.0. Conditions unfavorable for CH_4 production were assumed to have been caused by the infiltration. Changes in gas production rates due to changes in infiltration are evident as well in the results of Fungaroli and Steiner (1971), Ramaswamy (1970), and Songonuga (1970).

Refuse moisture contents approaching saturation have been shown to be necessary for maximum CH_4 production. However, the amounts and the chemical physical characteristics of moisture added to refuse to approach saturation may be such as to inhibit CH_4 production. Air added during infiltration may also provide inhibition.

4.3. Temperature

The effect of temperature on CH_4 production has been described in the context of the thermophilic, mesophilic, and psychorophilic ranges. Kotze *et al.* (1969) reported that CH_4 production during sewage sludge digestion was possible at temperatures ranging from 0 °C to 55 °C, but that maximum production rates occurred at specific temperatures within each of the three ranges, 37 °C being optimal for the mesophilic range.

Similar observations have been made concerning gas production in sanitary landfills. Dobson (1964) and Ramaswamy (1970) observed maximum gas production at 30 °C and 35 °C, respectively. Both found that gas production rates reduced with deviations from these optimal temperatures.

Some pattern appears to be present in the temperature variations in sanitary landfills. Immediately after refuse placement, a peak temperature is achieved as a result of aerobic decomposition (Rovers and Farquhar, 1972). Figure 2 shows that the magnitude of this temperature is dependent in part, upon the refuse temperature at placement. The time required to achieve this peak should be equal to the duration of Phase I, the aerobic gas production phase. Bevan (1967), and Merz and Stone (1969), Qasim and Burchinal (1970), Rovers and Farquhar (1972), observed peak temperatures after 1, 3, 5 and 9 days, respectively.

The maintenance of aerobic conditions in landfills creates sustained high temperatures. However, if the transition to anaerobiosis is made, the temperature reduces.

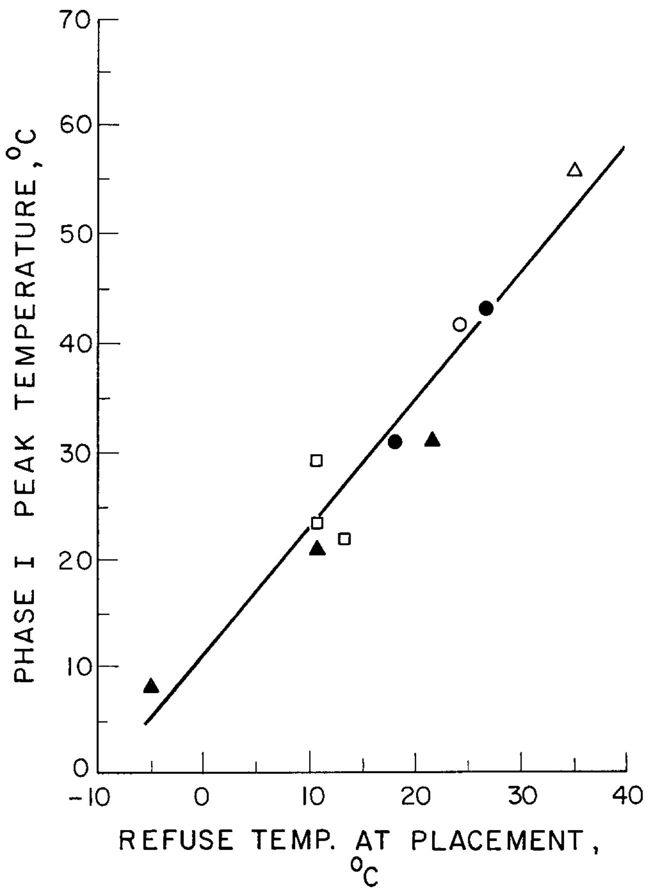

Fig. 2. Phase I peak temperature as a function of refuse temperature at placement. ○ Beluche (1968); □ Bevan (1967); △ Ludwig (1969); ● Qasim and Burchinal (1970); ▲ Rovers and Farquhar (1972).

Evidence of this appears in the work of Merz and Stone (1969) and Beluche (1968). Test cells of refuse were studied in parallel to observe the effects of aeration of refuse decomposition. The cell without aeration achieved an initial peak temperature of 43 °C and subsequent temperatures between 25 °C and 30 °C. The cell for which aeration was provided exhibited a peak temperature of 71 °C with subsequent temperatures near 49 °C.

It has been shown as well, that temperatures within the landfill fluctuate with long-term air temperature variations. Rovers and Farquhar (1972) found that in a southern Ontario sanitary landfill, the annual average temperature at a depth of 4 ft, (1.22 m) was 12 °C with seasonal fluctuations between 2 °C and 21 °C. These temperatures are significantly lower than those observed in the California studies (Merz, 1954; Merz and Stone, 1969; Beluche, 1968). They indicate as well, that anaerobic decomposition was taking place well within the psychrophilic range at temperatures much less than those considered optimal for CH_4 gas production. Thus, temperature is likely to play an important role in regulating gas production rates in sanitary landfills.

4.4. Alkalinity and pH

The optimal pH for CH_4 production during the anaerobic decomposition of sewage sludges is near 7.0. Deviations from this result in reduced gas production. An alkalinity in excess of 2000 mg l^{-1} as calcium carbonate is also considered optimal (Kotze *et al.*, 1969). While supporting data are scarce, these figures are assumed to apply for sanitary landfills as well.

Extremes in pH may arise from the existence of acid or alkaline materials within the refuse. Reductions in pH may also occur in response to an inhibition of CH_4 production with a resultant accumulation of organic acids. These would be accompanied by a reduction in alkalinity.

Rovers and Farquhar (1972) in their test cell experiments on the effects of excessive infiltration of leachate and gas production found that CO_2 was produced but that CH_4 was not. The pH remained near 6.0 initially. In the latter stages of their experiment, the pH reduced to 5.5, the bicarbonate alkalinity reduced to approximately 1500 mg l^{-1} as $CaCO_3$ and the NH_3 concentration reduced to 70 mg l^{-1} as ammonium ion at which time CO_2 production ceased. The addition of moisture was discontinued and at the end of two weeks, the pH, alkalinity and NH_3 concentrations had increased and CO_2 production has resumed. This sequence was allowed to continued in cyclic fashion. The reason why CH_4 production was inhibited was not determined although an unfavorable level of Eh was thought to have been the cause. Changes in the production of CO_2 seemed to be linked to variations in pH and alkalinity.

4.5. Refuse composition

It is certain that there exist many materials which are toxic or inhibitory to gas producing microorganisms and that these could find their way into sanitary landfills. In such cases, therefore, the composition of the refuse would play a significant role in the production of gas. It may also be the case, however, that conditions are such as to allow gas production to proceed but that nutritional deficiencies in the refuse impede the microbial population thus slowing production rates.

Ramaswamy (1972) found that gas production rates could be changed by varying the amounts of N_2, P, and K in the refuse. It is also known that carbonaceous materials yield a greater amount of gas than proteinaceous materials, but do so at a slower rate. A C:N ratio of 16:1 is considered to be optimal for CH_4 production during sewage sludge digestion (Kotze *et al.*, 1969). While such ratios must be applied with caution, it is clear that gas production rates will depend heavily on the organic material being decomposed. For example, gas production from the decomposition of paper with a C:N ratio of approximately 400:1 will differ from that of grass at a C:N ratio of 16:1. The physical condition of the refuse, particularly its size and surface area is also likely to influence decomposition rates.

Thus, the types and mixtures of materials within the landfill should exert effect on gas production patterns.

Figure 3 identifies the factors which appear to have the most significant effects on gas production in sanitary landfills. It serves to illustrate as well that a number of interactions can exist between these factors. The factors of group ‘A’ are features of the immediate microbial environment in which gas production occurs. The effects of variations in these factors have been discussed. The following example typifies the

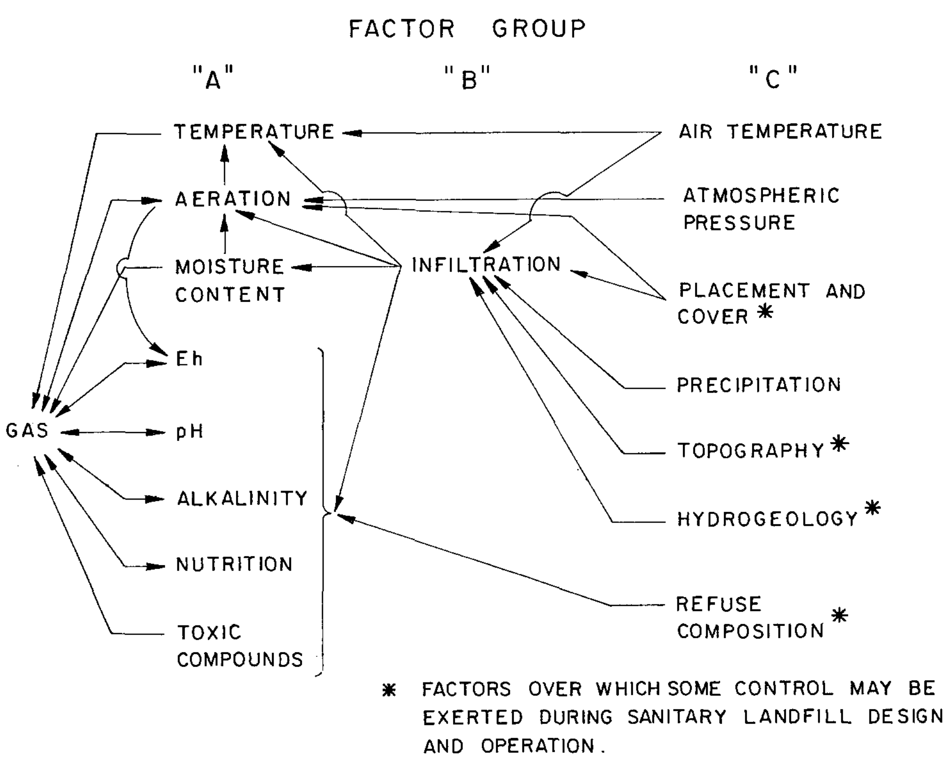

Fig. 3. Factors affecting gas production in sanitary landfills.

interactions which can exist. A reduction in temperature would impede CH_4 production. This would yield an accumulation of organic acids which would bring about reductions in alkalinity and pH. As a consequence, a reduction in pH could further impede the production of CH_4. A number of similar possibilities exist where variations in one factor affect another through a change in gas production.

The group 'B' factor, infiltration, depending on the amount of water infiltrating and its chemical physical characteristics, can affect virtually all of the group 'A' factors.

The group 'C' factors and their effects are described below. Air temperature determines, in part, refuse temperature. It also influences infiltration by affecting evaporation. Variations in atmospheric pressure can bring about exchanges between air and the gases within the refuse. Refuse placement and cover procedures and the materials used to furnish cover can affect the movement of both gas and water at the surface of the landfill. Precipitation affects infiltration as does topography, and the hydrogeology of the site. The composition of the refuse can influence several of the group 'A' factors, as shown. The group 'C' factors marked with an asterisk are those over which some control may be exerted in landfill design and operation. Manipulation of these would provide a means whereby gas production in sanitary landfills could be modified.

5. Summary and Conclusions

On the premises that sanitary landfilling will continue as a means of solid waste disposal and that the gases produced from landfills will remain problematic because of the potential hazards of groundwater contamination and explosion, it is important that landfill gas production and the factors which affect it be understood. The study described here was undertaken to assist this understanding.

Since information specific to the decomposition of refuse was sparse, use was made of information known about gas production in soil and in sewage sludge digesters. Factors affecting gas production and the levels of these factors for maximum production were established. The results of this activity were then used as a guide to examine the production of gas in sanitary landfills. Consideration was given primarily to conditions of anaerobic decomposition. A pattern for gas production in sanitary landfills was proposed covering the period from refuse placement to the attainment of maximum CH_4 production. The results from three studies involving experimentation with simulated landfills showed variations in the duration of this period from 180 days to 500 days. At the end of this period, the gases produced consisted of from 50% to 70% CH_4 and from 30‰ to 50‰ CO_2.

Again because of the scarcity of data, it was difficult to formulate firm conclusions about factors affecting landfill gas production. However, certain trends could be identified.

It was found that gas production in sanitary landfills increases with increased moisture content up to saturation. Data from several sources suggested that sanitary landfills, particularly at the time of refuse placement, are far from being saturated. It was found as well that infiltration into the refuse, depending on the amount and the chemical physical characteristics of the infiltrating water, could impede gas production. Increases in Eh in the immediate microbial environment were thought to increase during periods of excessive infiltration and therefore to bring about reductions in CH_4 production.

Gas production in sanitary landfills proceeds over a wide range of temperatures with maximum production rates occurring at 30 °C to 35 °C. Landfills, particularly those in northern climates, tend to exhibit temperatures which are much lower than this and which fluctuate with changes in season. Initial peak temperatures corresponding to a period of aerobic decomposition are reached during the first month after placement. The magnitude of this peak depends in part on the temperature at placement provided that subsequent aeration of the fill does not occur. The peak temperature is from 10 °C to 15 °C higher than the placement temperature.

The optimum pH for land gas production appears to be near 7.0. Data available from one source showed that all gas production ceased at a pH of 5.5. A resumption in CO_2 production accompanied an increase in pH to 6.0.

Refuse composition is considered to be important since information exists to show that modifications to the chemical composition of the refuse can bring about changes in the gas production rates.

A schematic representation of the factors which affect landfill gas production and how these may interact was developed. Those factors over which some control can be exerted through proper landfill design and operation were identified.

The results of this study were presented primarily as trends. They suggest behavioral patterns of landfill gas production in response to the various factors considered. Additional experimentation is required to determine quantiatively the magnitude of these responses to specific ranges of factor variation.

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