PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

IMPLICATIONS OF WASTE TREATMENT PROCESSES AND ARCTIC RECEIVING WATERS

R. Sage Murphy, Ph.D.
Director
Julian K. Greenwood
Graduate Research Assistant

Institute of Water Resources
University of Alaska

College, Alaska
U.S.A.

INTRODUCTION

The emerging status of North America's Arctic and sub-Arctic is continuing to cause national and international debates on possible environmental degradation to a fragile and rare ecosystem. The most frequently heard fear centers around oil spills-petroleum, of course, being the prime reason for most existing activity in the Far North. A close second is the fear, or concern, for disturbing the protective tundra overlying the permafrost and the ensuing erosion, failures to man-made structures (including pipelines, which again puts the oil spill problem back into the forefront), and alteration of natural migration paths and breeding areas of various arctic and sub-arctic fauna. The problems of domestic waste treatment and disposal are mentioned occassionally. The input of these wastes will be continuing and not of the catastrophic oil spill nature. They may (or may not) have an influence on the ecological balance of water resources. They are, however, of paramount concern to the public health of the humans working in the area. On a total weight basis, these waste discharges will, in the long run, far outweigh any pollutant created by a catastrophic event. Of course, the total duration of any event is significant and the authors' point is simply to focus on waste treatment and its implications.

This paper was not prepared to summarize an ongoing or recently completed research project. Rather, it is a report describing, in a general way, some of the problems of waste treatment and disposal in arctic Alaska, mainly the Prudhoe Bay region (See Fig. 1). A premise upon which this report is based concerns projected populations for the whole North Slope. Communities with populations greater than 1,000 - 2,000 persons will be rare, and total population will probably not exceed 10,000 on the North Slope in the foreseeable future [1,2]. Greater populations than this may be present for short periods during construction activities, however.

Although this paper is largely about the disturbances to freshwater bodies the remarks have a great deal of relevance to those concerned about the condition of Alaska's coastal zones and estuaries. In fact, much of the oil development can be considered to be taking place in estuarine regions, since during the late fall and winter months, when river flows in the Arctic virtually vanish, seawater intrusions have been measured up to 50 kilometers from the coast. Furthermore it is likely that the low biodegradation rates in cold waters and the high spring and early summer river flows lead to a situation in which any waste material pumped into arctic streams at this time of year is largely degraded in the very shallow coastal zone, rather than in the rivers themselves.

It is fortunate that the industrial development occurring in the Arctic is petroleum and not a labor intensive industry. Although oil pollution will always be a threat to the environment, few problems should exist due to domestic wastes. North America's greatest polluter, agriculture, has no chance of survival in the area. To read the popular press, however, one would believe that Alaska is intentionally pursuing a path to the total destruction of the arctic ecosystem. Accounts of other developments and pollution incidents on a world-wide basis have been succinctly reported and misrepresentation of information corrected by Korringa [3]. A similar concerted effort is now in demand for Alaska's Arctic.

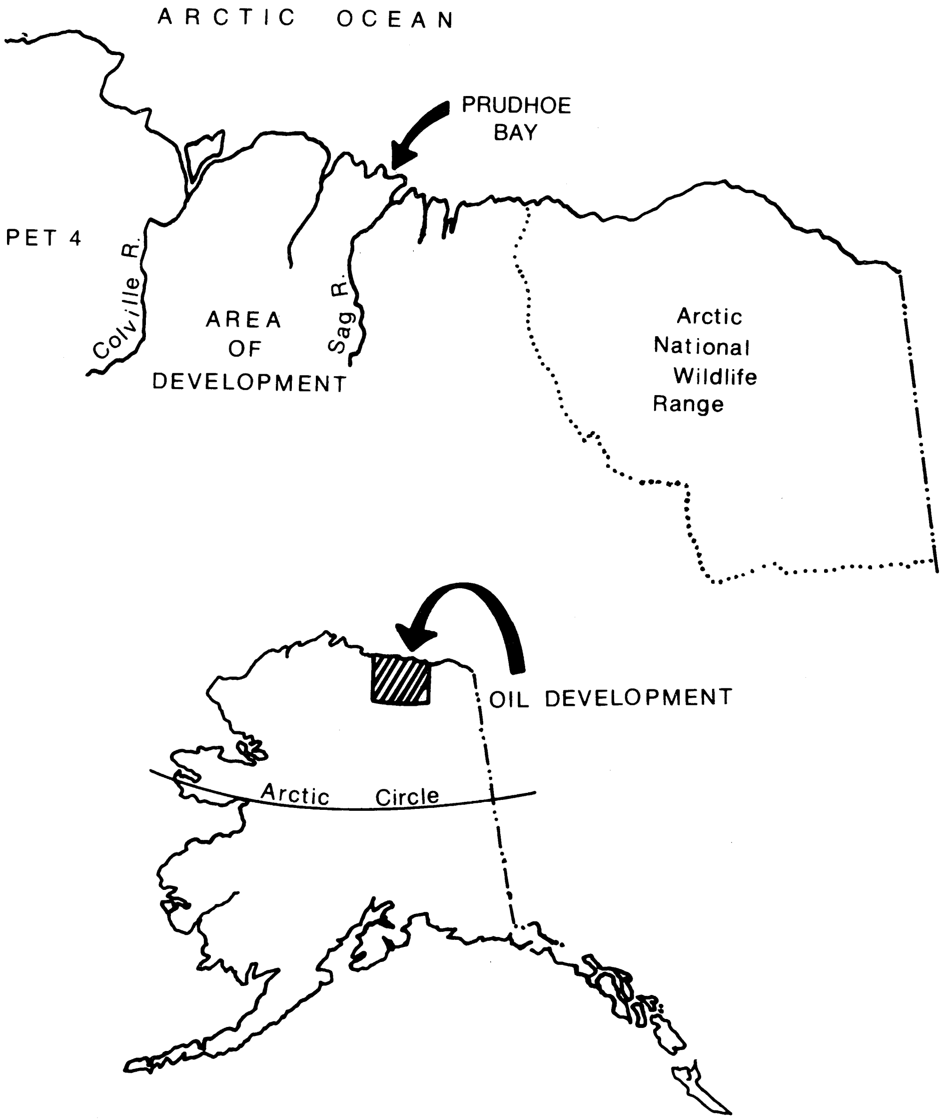

FIGURE 1 Prudhoe Bay Region

The present level of concern about the Arctic and the damage that careless development could cause has been prompted in part by historical experience. The U.S. Navy maintains a reserve of land (37,000 sq. mi.) west of the Colville River called the Naval Petroleum Reserve No. 4, which they explored for oil and gas between 1945 and 1953. Numerous observers travelling in the region since those years have reported mounds of trash left behind, disused oil drums which have continued to leak oil and damage wildlife years afterwards, and frequent examples of surface erosion and settling after mechanized equipment had travelled over the land and disturbed the surface vegetation. A graduate student at the University of Alaska devoted an entire research thesis [4] to the damage left by these truck and caterpillar trails, many scars still visible 25 years after they were created. Today the public is much more aware of this problem and officials are determined that it will not be repeated.

The official viewpoint reflects a demand for high standards of waste disposal. The State of Alaska's Division of Environmental Health has set out objectives [5] for operation of water supply and waste disposal into Arctic Slope waters which have some very still clauses effectively prohibiting the discharge of any wastes which have received less than full secondary (or biological) treatment. The guidelines also suggest central management of all solid wastes so that the past record of tundra-littering by the garbage and oil drums of geophysical crews is not repeated into the future. It is clear that this is one industrial development which is being very closely regulated.

The industry, on their part, seems to be complying fairly stoically to controls over their operations that might have been thought inequitous and discriminatory if comparisons were to be made with industrial operations elsewhere or to domestic operations within the state. But there are good arguments for not comparing the Arctic Slope oil development with similar developments; not only are the environmental conditions qualitatively different from conditions elsewhere, but the Arctic has been so little studied that no one can offer much more than some good guesses about the likely effects of careless operations. In fact there have been an enormous number of public statements in the last two years in which such likely effects have been alternately described as "catastrophic" on one hand, and "negligible" on the other. Apparently not everyone's guesses have been good.

BACKGROUND

For any not familiar with Alaska's Arctic Slope, it is worth digressing to describe some of the peculiar conditions which are pertinent to waste treatment. Most of the development north of the Brooks Range is taking place on what is known as the Arctic Coastal Plain - an extremely flat plain extending some 50 miles inland, speckled in the summer with thousands of shallow lakes, most of them less than 2 meters deep, and covered fairly uniformly with a marshy grasslike, "wet tundra" vegetation. More detailed descriptions of vegetation types are available, the reader being referred to Spetzman [6] in particular. It is underlain everywhere with over 1,000 feet of permafrost. A number of rivers twist across this plain in broad braided paths, their channels moving slightly from year to year as their heavy spring sediment load is deposited along the route. These rivers, even the biggest ones, exhibit extremely large variations in flow as the seasons progress. For most of the year, from October to June, there is no measurable flow. The ice cover on all surface waters builds up to about 2 meters, and while many of the larger streams retain pools of unfrozen water below this depth, this water is apparently nearly stagnant. The spring melt, in early June, comes as a great contrast. Fully 50% of the annual flow may reach the sea in the first month of flow. Along its banks this turbulent flow scours and erodes the gravel bed, picking up enormous amounts of silt [7]. The water temperatures hover near 0° C for 9 months of the year and probably achieve maximum temperatures over 10° C for less than a month. By all the standards of more temperate waters, arctic streams represent a harsh environment for life; only a small number of well-adapted species could be expected to survive.

Very little is known as yet of the ecology of arctic waters though there are a number of studies being pursued at present which should shed some light on this area. Of particular interest is the fact that the dissolved oxygen is known to drop to very low levels under the winter ice, and though data is not yet available, concentrations of DO less than 1 mg/l may be widespread. Yet bacteria and insect larvae are known to survive in the streams [8], and some species of fish, notably the arctic char, have been found to winter in these rivers. One can expect to discover that such organisms have learned to survive very low oxygen tensions - levels which would have been considered critical to aerobic life in other, more temperate streams. The obvious conclusion is that an arbitrary stream standard based on dissolved oxygen as a water quality parameter cannot be used. Rather one should determine whether the oxygen requirements of organisms vary with the season, or whether they somehow contrive in winter to congregate in regions of the streams where DO levels remain for some reason rather higher. In the same way a stream standard for suspended sediment makes little sense, in view of the very high levels which occur naturally. Man needs gravel in the Arctic for road building, and he normally mines it from the stream beds where it is very plentiful. But it seems doubtful that the increased sediment load he causes from such activity could be serious beside the natural erosion processes. The dangers in gravel mining from river beds are expressed by scientists who fear the disturbance of benthic organisms or fish spawning beds, and one hopes that a little on the spot research will settle this question fairly rapidly.

Man in the north has imported almost every aspect of his life-support systems - with the possible exception of his clothing, which is borrowed from the Eskimo. He has also imported his waste treatment systems from the south, and as one might expect has experienced some difficulty adjusting them to the cold climate conditions. It seems that a kind of perverse law operates in the Arctic; most chemical, biological, and physical processes on which the familiar treatments depend are critically slower at cold temperatures. Furthermore, the maintenance of mechanical equipment under severe winter conditions becomes a recurring problem. By and large the reaction of designers has been to house treatment equipment in heated buildings and in this way attempt to sidestep the problem - in most cases this seems a very sensible approach, though it is costly. One learns to assume that when the weather is at its worst, the equipment will break down. If the plant is not housed, then it may be physically impossible to repair the fault adequately, and even if the repairs are accomplished, a biological system may prove very awkward to restart. There are so many good reasons for housing the treatment plant for an arctic camp that one can almost predict that one which is left uncovered will certainly be ineffective.

WASTE TREATMENT AND ULTIMATE DISPOSAL PRACTICES IN THE ARCTIC

Since maintenance problems and the lack of skilled manpower are chronic operating disabilities of the far north, there is a tendency to shift to the simplest possible systems. Aerated lagoons are finding some popularity in outlying areas of sub-arctic Alaska, and it is possible that they might have application in the Arctic, though the authors have reservations on the subject, as does the State of Alaska's Division of Environmental Health which does not approve of such treatment devices in the continuous permafrost regions north of the Brooks Range. Although Pick, et al. [9] and Reid [10], among others, have reported in detail on operating efficiencies of aerated lagoons in northern Canada and interior Alaska, certain basic problems exist in their use in the true Arctic. Recent surveys of lagoons of this type, all using submerged tube diffusers, have been conducted by the Alaska Water Lab, an arm of the Federal Water Quality Office, and by the Arctic Health Research Center of the U.S. Department of Health, Education and Welfare. These studies indicate that aerated lagoons are feasible, that they achieve between 45% and 65% removal of BOD_5 (measured at 20° C) and that they require rather less operator skill and maintenance than any other treatment method. There are, naturally, some important reservations to be borne in mind. A lagoon which is constructed on permafrost will create a thaw bowl, and may result in uncontrollable erosion if great care is not taken with construction. [It might in some cases be possible to use an existing shallow lake for a lagoon, and avoid this problem]. The diffuser tubes have an annoying tendency to clog in Alaska's high carbonate waters, and may be rendered ineffective for some months on this account. Another factor is the continuous summer daylight which has been observed to cause excessive algal growth in the month or so after the ice has melted. The winter has usually been a period of relative inactivity during which unstabilized sludge has accumulated in anaerobic regions of the pond. This sludge is rapidly oxidized in the first flush of summer, and the heavy algal blooms are the result. If these algae are allowed to escape in the effluent very little treatment is being accomplished, particularly if the effluent has been chlorinated.

Largely because of the risk of permafrost melting along with the requirement of correct operation, aerated lagoons seem a second-best solution for the "industrial" Arctic. The state requirements of 90% reduction of BOD and the advisability of housing the critical components of biological treatment systems lead one to recommend some modification of the *activated sludge process* in preference to lagoons. Where the lagooning method of treatment is more or less an imitation of nature's purification methods, the activated sludge process attempts to improve on nature by building up an extremely high concentration of biological material in a well mixed and aerated reaction tank, and therefore treating wastes at a much higher rate than is possible in a lake or a lagoon.

The process is one of converting the soluble or colloidal organic materials in the sewage into a biological mass which at high concentrations will flocculate, and is readily settled out in a separate sedimentation tank. The floc is then returned to the reaction vessel to keep the biological concentration high, while the supernatant is discharged either to a stream or a storage lake. Any remaining organic matter in this effluent is in theory not objectionable, as it is material which has proved resistant to biological attack, and it will be even less degradable at stream temperatures. Detention times will be of the order of a few hours (instead of many days), and thus the sizes of the tanks required will be small enough to house at reasonable cost.

There is another important advantage associated with short detention times, which is the reduced heating requirement. If sewage is moving through the plant fast enough it will contain enough heat capacity to keep itself from freezing and in fact to keep its enclosure at a fairly even temperature without artificial heat, except during breakdowns. In Fairbanks, where mid-winter temperatures are rather more severe than on the Arctic Slope, Grube and Murphy [11] demonstrated that an oxidation ditch exposed to ambient temperatures had no surface ice formation, simply because the sewage inflow was fairly warm. This additional heat was adequate to prevent freezing even at detention times of two days.

The impression that aerobic biological treatment is necessarily inefficient at water temperatures near freezing should be dispelled. Unpublished findings of research conducted at the University of Alaska's Institute of Water Resources, and data of Eckenfelder [12] and Eckenfelder and Englande [13] indicates that there should be no reduction of efficiency in an activated sludge plant due to temperature alone. The reasons for housing treatment units are largely the pragmatic ones of easing maintenance problems, and avoiding the breakdown of mechanical equipment. However, anaerobic treatment appears to be crucially slow at low temperatures, as a number of researchers have pointed out. For this reason such processes as the septic tank are not recommended for arctic use. Not only are they rarely more than 40% efficient since they are in practice little more than solids-liquid separating devices, but the problem of disposing of the outflow may be insuperable in permafrost regions, as pointed out by Hickey and Duncan [14].

The problem of ultimate disposal of wastes looms large in the Arctic, no matter what treatment system is used. Whether one is confronted with the disposal of wastes onto the tundra, or separation and concentration of the "objectionable" portion of the wastes by some process, nearly the same total quantity remains to be dispersed of. Thus, waste handling and management, versus simply treatment, often becomes the paramount engineering consideration.

A major public health aspect is the almost indefinite survival time of pathogens (bacteria and/or viruses) in the frozen state. If they are permitted to escape onto the tundra in winter, there is a real risk of disease transmission through animals. The best solution, albeit an expensive one, would be to combine secondary treatment with incineration of secondary sludge. The chances of air pollution problems developing on the rather windy Arctic Slope seem negligible if the incinerators are positioned downwind of camps. Incinerators can also be developed in convenient package form suitable for simple movement from place to place [15].

A difficulty with treating wastes at remote sites anywhere in the world is the necessity of dealing with low and variable flows, and equally variable waste concentrations. To give some examples, average waste flows for large U.S. cities are near 150 gallons/capita/day, whereas outlying camps in the arctic may be as low as 30 gals/cap/day. The latter, of course, will be proportionately stronger, perhaps averaging 750 mg/l of BOD_5. More trying, however, is the wide diurnal flow variation; there may well be no flow at all for two or three hours in the early morning. Biological treatment systems tend to react badly to such variations in loading, and this will influence the choice of treatment system.

Mention should be made of physical-chemical treatment, which shows great promise for small flow applications such as those being discussed. This treatment relies on chemical precipitation, chemical adsorption, and filtering to remove unwanted materials from the wastewater. However the problem remains: what happens to the accumulating chemical sludges and filtered solids? Again the answer may very often be incineration.

Although the expenses of chemical-physical processes far exceed those of biological processes, some possible advantages might exsist for the former even though their overall efficiency is no greater than found in biological systems when both are operating at design efficiency. Again, the key element is operation. It is unlikely that a qualified operator will be found who understands the complexities of a biological treatment plant, particularly in remote areas. However, the typical chemical-physical process is usually not so foreign to maintenance personnel at such sites and reasonable operation might be expected.

WATER QUALITY MANAGEMENT

The management of water quality in the Arctic, then, is based on a management of effluent quality, rather than on stream standards. However, the setting of reasonable effluent standards raises some questions of equity. Is it necessary to treat effluents to the same degree at all sites and at all seasons of the year, when it is clear that the receiving waters are undergoing enormous changes in their physical and chemical conditions, and in their assimilative capacities? This question is hard to answer, since no studies have been pursued to directly answer the question, "What is the assimilative capacity of an arctic river?"

One can speculate, however, that if a camp were to store its wastes all winter long and discharge them into the nearby river during the spring floods, that these wastes would be very effectively diluted and swept to sea with negligible damage to anything. A useful research priority might be to establish this "assimilative capacity" through an actual field test on a small arctic river.

A second question of equity arises when one compares the activities of small, temporary operations (typically the geophysical parties, or even research teams) with those of a more permanent nature, such as the permanent camps near producing wells. These exploratory rigs may consist of forty men, who may work an area without striking oil for 3 months, and then leave. It seems to be an unnecessary burden on a survey party to require them to apply secondary treatment and incineration to all their domestic wastes. Yet they should clearly not be given a free hand to despoil the land and waters around them. The problem of where to draw the line would be more easily answered once more about the assimilative capacity of the arctic waters is known. In the meantime they are being asked to contain and remove as much of their wastes as is possible for disposal elsewhere.

The need for just and uniform policies on water quality management of the Arctic Slope, and the desirability of establishing research priorities in the area seem to indicate the formation of a regional management concept for the entire Arctic Slope region. The policy-making management group would initially consist of a semi-formal committee of oil company personnel, and State and Federal environmental health agents. Such a group would be in an improved position to recommend and fund high priority research, and to adjust operation standards as new information emerges and as man's experience of north increases. This group would be in a position to guide the overall development of the region in a coordinated fashion; it would recommend sites for base camps from consideration of its data on water supply and waste disposal possibilities, and from its access to the results of all ecological research in the area it would be able to preserve those areas of greatest importance to wildlife. In all probability the regional management philosophy would be extended to include all land use decisions, since they bear so intimately on water use and water quality. It is felt that such a regional approach would be of great value in allowing speedy but responsible development of the North Slope.

CONCLUDING REMARKS

I. Existing technology is adequate for the treatment of any wastes originating in North America's arctic regions.

II. Pollution problems arise from handling technology in very cold areas. Additional problems are caused by maintenance and operation difficulties encountered in the rather small installations. This is a difficulty of small plants, however, and not necessarily of climatic region.

III. Considering the low populations existant and projected, waste treatment practices are more relevant to public health than to ecological considerations.

IV. Comprehensive basin-wide, or, better, Slope-wide, water and land management appears imperative from both economic and technical grounds. Management of the research effort as well as the use of the resources is called for during the first stages of arctic development.

V. The following point was not made in the text but is appropriate for the final remark. Regardless of the United States' concern over the arctic environment and the adjacent waters of the Arctic Ocean, if the region should expand to a greater degree than presently anticipated, their efforts will be useless (and uneconomical) unless they are in accord with our neighbors to the east and west. When the arctic coastline is compared with those of the Soviet Union and Canada, one realizes that the U.S. efforts toward protection of this ocean system could be wasted unless all circumpolar countries are in accord. The reverse, of course, could also be true, but present evidence does not point to this conclusion.

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QUESTION by Colonel Ray S. Hansen, Department of the Army Corps of Eng., Buffalo, N.Y., USA,
concerning paper by
Dr. R. Sage Murphy, Institute of Water Resources, College, Alaska, USA.

Do you have any experience with aerobic lagoons becoming anaerobic during the winter ?

ANSWER by Dr. R. Sage Murphy.

Yes, but this was because the lagoons were overloaded. With proper operation it need not happen.