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# SOME PRACTICAL ASPECTS OF THERMAL PLUME ANALYSIS

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## ABSTRACT

It is desirable to perform thermal plume analysis with as low an expense of effort and cost as is consistent with complete and accurate results. This is only possible by prior consideration of local geography and conditions. A description is given of a method of plume temperature measurements in polar coordinates which reduces manpower and equipment requirements for point-source thermal discharges, as compared with measurements in cartesian coordinates. Boat and water safety is discussed, especially regarding dam proximity. Types of access to rivers are described, including precautions to be taken in their choice.

The effect of hourly background temperature variations upon measurements is described, together with depth variations in background temperature. The magnitude of such variations is compared to statutory limitations. Deep river currents are described, especially in the vicinity of dams, backwaters, and obstructions, which may produce anomalous plume shapes.

## INTRODUCTION

It is desirable to perform thermal plume analysis with as low a level of effort and cost as possible as is consistent with complete and accurate results. This is only possible by consideration of local geography and conditions. The examples I will use today are based upon thermal discharges from fossil fuel fired power plants, and gray iron foundries, to Iowa Class B warm rivers [1].

## ACCURACY

First let us discuss precision and accuracy. Remember that precision is a measure of repeatability. Accuracy is the difference between the "true" value of a measurement and its observed value. There are two related types of accuracy to consider. The first is instrument accuracy. The term "instrument" includes any device for measuring temperature or displacement. This includes transits, thermometers, thermistors, meters, sounding ropes, and tether ropes. The second is the accuracy required by regulatory agencies. Temperature accuracy is requested to be ± 0.1°C. Displacement accuracy is generally accepted to be ± 1 foot or ± 1%, whichever is greater [2].

I would like to describe the method of position measurement which we use, and limit the discussion of accuracy to the implements used in this method. First, two points are established, one at or near the discharge point, and one sufficiently removed to determine an accurate line on a plat plan, aerial photograph, or enlarged topographical map. We use wooden stakes painted with fluorescent orange paint to mark such points. Typically, the two stakes are 20 feet apart. Then maintaining a constant radius of 20 feet, other such stakes are set at angular displacements of ten to twenty degrees, depending upon the type of plume expected. These angles are measured by describing sequential isosceles triangles with stakes at the verticles, knowing two sides of the triangle and the desired angle. We believe the stakes can be placed with a cumlative displacement error of 0.5 inches. The stake near the mooring point, known as the master stake, is also the mooring point for the boat. A nylon braided rope of 3/16" diameter is attached to the bottom of the stake and the reel for the rope is placed in the boat. This line is knotted and marked every ten feet, much like a sounding line. Two persons are then required in order to perform the work: one to pilot the boat and achieve visual alignment with the stakes, and another to take and record temperature measurements. With the outboard motor in reverse to maintain slight tension on the mooring line, the boat is swung in an arc at each radial displacement, stopping as it comes into alignment with the master stake and one of the angular stakes long enough to take temperature measurements. The boat is then let out to the next radial displacement and the process is repeated. When temperature measurements are below the required contours, the data collection is complete.

We described the method here in the context of accuracy. Angular errors remain the same regardless of radial displacement, but by similar triangles, convert to proportionally larger arc error, measured in units of length, as radial displacement increases.

About the longest length of rope we like to play out is 200 feet. Let us take this as worst case: if the maximum stake position error is assumed to be 0.5 inches of arc at 20 feet, at two hundred feet the error converts to 5.0 inches. Assuming that at that distance we lose another 0.5 inches of accuracy due to sighting error, our cumulative arc error is ten inches. The error in the radial dimension is primarily due to stretching of the rope. Nylon rope will stretch slightly further with a given tension when it is wet, due to the lubrication of the water between the nylon fibers. With the size and type of nylon rope we use, we have noted that a stretching of about 1% is observed. When the knots were located, the rope was stressed with ten pounds of force, as an average of the reaction from outboard motors at various power settings. The use of wire aircraft cable might improve the situation, but is more difficult to handle in the boat due to its lack of suppleness. At any rate, at two hundred feet, we will observe a radial diaplacement error of about 2 feet. With this information, we can see that on a practical basis, it is possible to obtain an absolute displacement accuracy of ± 1% or ± 1 foot, whichever is greater.

The discussion of temperature accuracy is more straightforward. Although research instruments are available for accurately measuring temperatures less than 0.001°C, Hardy field instruments for use under sometimes rigorous conditions found during thermal measurements usually cover a fairly large range of temperatures, with a large time constant. Whereas they are reported by their manufacturers often to be accurate to 0.05°C, the problem with most instruments is meter readability. With our instrument, the meter is accurately reading to ± 0.1°C, which we use as our accuracy standards [3].

We have discussed these field capabilities with the United States Environmental Protection Agency personnel from Region VII, Region IV, and Corvallis, as well as state agency personnel, and have found no objection to these accuracy limits. It should be observed that no written regulations are presently in effect which stipulate accuracy requirements [2].

## LOGISTICS

I should like to turn your attention to field logistics for a few moments. Since the purpose of this paper is to describe methods of reducing manpower requirements, I would like to emphasize the necessity of careful planning. A few minutes spent in the office with a checklist will often save hours in the field. Be certain that the boat you intend to use is available on the day that you intend to use it. Be certain that it is licensed by the proper authorities and is in good repair. Even if these activities are the responsibility of the central stores department, the quartermaster, or some other person, it is your time and/or that of your personnel which will be wasted if proper planning is absent. The same applies to the outboard motor. Will it run properly at all power settings, especially low ones? Is it in good repair? An engine which stalls at idle power and is difficult to start when hot can be a safety hazard as well as a waste of time. Is there a proper access to the river within a reasonable distance? Is it in good condition? If you are using a boat trailer, remember that it may be easier to winch the boat two or three extra feet than to move a vehicle which has been mired down in clay or mud. Do you have a supply of shear pins for the outboard motor? They are easy to shear if working around stumps or snags, and difficult to find when in the midst of a thermal study. Have you taken all the proper equipment with you? For our procedures we use the following check list:

Vehicle and trailer
Boat, motor and fuel
Oars
Life jackets
Seat cushions
Temperature meter
Accessory cable for meter
Stakes
Mooring line
Security chain and lock
Laboratory notebook
Writing instruments
Shear pins
Steel tape measure
Camera

The camera may be optional. The writing instruments are not. We recommend both a pen and a pencil. With due respect for the fact that all entries in a laboratory notebook should be made in ink, at times it is necessary to perform a thermal plume study through a drizzling rain. At times like these, a pencil will write when a pen will not. The data can then be copied in ink at a later time with appropriate notation.

SAFETY

I should now like to address myself to boat safety [4]. First, it is important to remember the elementary rules for pleasure boating. Sometimes we who are involved in technical work forget about these from time to time, to our peril. Do not overload the boat. This should be no problem with two persons and a fourteen foot, or larger, craft. Do not overpower the boat. Remember that the engine will be running in reverse most of the time, and then close to idle power. We have used everything from a fourteen foot round-bottom to a twenty foot flat-bottom, powered from 25 horsepower down to 4 horsepower. Frankly, we favor the lower power ranges, and see no need to use an engine larger than 8-10 horsepower. Keep the center of gravity near the centerline of the boat. This is especially important during boarding or leaving the boat. Make certain that you have all proper safety equipment, including oars, life jackets (being worn), lights if necessary, and a fire extinguisher if applicapable to your engine size. Keep away from obstructions in the river. Use the mooring line wherever possible, except when moving your radius, and then be careful not to kill the motor or break a shear pin. Be careful when approaching a rocky shore. Have the person in the bow of the boat prepared to jump out or to lay hold of a mooring device, to protect the bow. Now about dams: We have an internal rule not to work closer to a dam than 50 feet, and then only when secured by the mooring line. The sole exception to this is where most of the water flow is over a spillway and there is no possibility of a loaded boat going over said dam. The only time we have made this exception was during the extremely dry weather in the midwest last year. There exist two possible circumstances under which personnel perform thermal plume measurements. Either they are employed directly by the discharger, or they are not. The latter group would include personnel of consulting firms such as ours, or staff of regulatory agencies. We approached the Occupational Safety and Health Administration and the Iowa Department of Labor regarding their requirements. The consensus is that no specific activity requirement is in effect at this time. The closest that OSHA can come is under maritime regulations, and then under the sub-heading of longshoring [5]. Under section 1910.16, "longshoring operation is the loading, unloading, moving, or hauling of cargo, ship's stores, gear, etc. into, in, on, or out of any vessel". It may be stretching things a bit to describe thermal plume analysis as longshoring, but if any person performing any of this work is a member of a longshoreman's union, it would bear looking into part 1504 of the standards [6]. At any rate, I was asked to emphasize that no employer is exempt from section 5.(a)(1) of the act itself, which states that:

> "Each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees."

Simply stated, all uf us, whether affliated with industry, consulting firms, or regulatory agencies, must take every conceivable precaution to prevent accidents.

## BACKGROUND TEMPERATURE VARIATIONS

The next topic relates to variations in background temperature. Since thermal controls are composed of temperature differentials between background temperature and observed temperature at given points, it is mandatory to know exactly what the background temperature is. At any one point, we will observe decreases in temperature from 0.5°C to 1.5°C between the surface and twelve feet of depth. In addition, depending upon cloud cover and season of the year, background temperatures at a given point may increase as much as 2.0°C during the course of a day. Since we are often attempting to define the 2.8°C contour $\pm$ 0.1°, it may be seen that background temperatures should be checked often, and the time of actual measurements should also be recorded. Only in this way can accurate contours be drawn.

## UNUSUAL PLUMES

The last topic which I wish to cover is that of making certain that all necessary data is taken. In a relatively shallow and flat river, this is no problem because the plume assumes a conventional shape, and measurements can be taken at a point until within the required contour. If the river is deep and slow and/or fraught with obstructions, or has unusual channeling, some attempt may have to be made in the field to visualize or "chase" the plume. At or near the twenty foot level near the base of a dam, a current of condenser water eddied, to come to the surface a considerable distance upstream. On the other hand, a plume may disappear as it goes over a dam due to mixing, or if part of it is drawn through a turbine intake. A bend in the river can cause the plume to hug the bank for hundreds of feet, and make multiple-origin measurements necessary.

If, however, all data necessary is taken and recorded in an accurate and safe manner, the task of writing the report is considerably minimized.

## REFERENCES

1. State of Iowa, Department of Environmental Quality, Iowa Departmental Rules, Chapter 16.

2. United States Environmental Protection Agency, Regions IV and VII, private communications.

3. Yellow Springs Instrument Company, Inc., Yellow Springs, Ohio. Model 33 SCT Meter.

4. United States Coast Guard, Boating Safety Regulations.

5. Federal Register, Thursday, 27 June 1974. Volume 39. Number 125 part II. Department of Labor, OSHA Standards.

6. Code of Federal Regulations, Title 29, Chapter XVII, part 1504.