A RAIL EMISSION STUDY: FUGITIVE COAL DUST ASSESSMENT AND MITIGATION

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ABSTRACT

A four-year study on fugitive coal dust emissions has produced estimates of coal loss during rail transport and developed suppression techniques that can reduce dusting from rail cars by 95 to 99%. The critical issues of emission characterization and material loss quantification had to be resolved before cost effective dust control strategies could be implemented and evaluated. Laboratory assessments, computer-based simulations, and field experiments were used to model and quantify coal dust emissions. These methods revealed coal losses along a ~500 mile-long rail corridor of up to 0.6 tons/car, with typical losses of 0.2 to 0.4 tons/car from metallurgical coals occurring under sunny, dry and windy conditions. A combination of load-top grooming, surfactants, and chemical binding agents proved to be the most effective method for reducing fugitive coal dust emissions during transit.

INTRODUCTION

Fugitive coal dust from in-transit coal cars does not appear to violate ambient air-quality standards. In fact, track-side monitoring of PM-10/TSP yielded no firm basis for remedial action. At issue, however, is the railroad's goal to reduce coal dust emissions and their impact as a nuisance pollutant.

Most of the evidence of fugitive coal dust emissions comes from anecdotal reports of dust plumes or the observations of coal deposition along the rail corridors. Without any standards of objectivity, coal dust complaints have given rise to the perception of significant a coal dust problem. Accordingly, a study was designed to relate the perceived problem (i.e., visual emissions) to the existence of quantifiable material losses (i.e., material losses that may represent significant environmental impact and/or financial consequences).

Previous attempts to quantify material losses produced mixed and controversial results, (Brown and Speichert, 1976; Guarnaschelli, 1977; Hardy Associates, 1979; Cope, 1980; McCoy, 1980; Williams, et al., 1982; Nobel, et al., 1983; Morrison, Hershfield Ltd., 1983; Cope, et al., 1984; Swan Wooster Engineering Co. Ltd, 1985; Environmental Sciences Ltd., 1985; Cope, et al., 1986; Wituschek, et al., 1986; Stewart, et al., 1987; Mikula and Parsons, 1988). Therefore, the characterization and quantification of losses along Norfolk Southern's (NS) rail corridors were identified as critical issues to be resolved before prescribing effective control strategies. Since early 1991, NS and Simpson Weather Associates (SWA) have conducted numerous laboratory and field-rail experiments to assess the magnitude of material losses and develop techniques to mitigate fugitive coal dust emissions during transit. A coal shipper, CONSOL also contributed to the field studies. This paper presents an overview of the study's ongoing efforts and results to date.

GENERAL STUDY APPROACH

The Norfolk Southern Rail Emission Study (NSRES) was conducted within one rail corridor, through which primarily export metallurgical (met) coal was transported. The choice of the rail corridor was based on its variety of terrain, relatively heavy volume of coal traffic, and the number of coal-dust complaints received. Metallurgical coal was chosen since, in most cases, it is considered more dusty than steam coal.

Field Trials

In an attempt to overcome some of the problems encountered in previous studies, the NSRES employed a number of independent field measurements to 1) act as quality-assurance checks within data sets, 2) to identify and understand aberrant measurements, and 3) to corroborate findings between data sets. Much of the early field data was gathered using a specially designed research caboose. As the study progressed, the instrumentation became more compact, thus reducing the need for the research caboose.

Scale Weights

The first of the field data sets is car weights. These weights were measured using static, decoupled, electronic scales. The scales have a reported accuracy of 0.01%. The weights were taken of selected cars before transit and then again after transit. As a reference, a scale monitor car that traveled with each weighing experiment was weighed at both locations to determine a scale correction factor. In addition, a tarped coal car was used, on occasion, as a second reference. It was assumed that no coal was lost during transit from the tarped car, and moisture loss and gain was minimized. To accurately evaluate the weight changes in coal cars moving from mine to port, moisture variations were taken into account. To account for moisture changes, a water budget was developed containing all known variables of moisture movement in and out of coal cars. Measured rainfall and estimated evaporation values were assigned to the water budget variables so that moisture changes could be used to adjust the scale weight differences. Moisture change correction factors were also empirically generated from coal samples collected in the field. In spite of all the precautions taken to assure accurate scale weights, an uncertainty in coal losses $\pm$ 200 lbs. still remains. This is most likely due to inherent scale inaccuracies and moisture changes that cannot be precisely measured, such as water dripping out the bottom of hopper doors. Because similar problems with scale weights have been encountered in other railroad work, we decided not rely on scale weight changes as the sole determinate for material losses. Rather, we used scale weights and three other methods jointly to arrive at a material loss estimates. These other methods are described below.

Load-top Volume Changes

The second method used to estimate material losses involved measuring the volume changes on the top of the coal loads from the mine to port. For the first several fields trials, a series of photographic transects were taken in selected coal cars at various points along the rail corridor. Scaled photographs of the same cars were compared throughout the trip and material losses were calculated based on volume losses within a given car. Coal within each car settling was taken into account and samples were taken to obtain bulk densities for the mass-loss calculations. It should be noted, that as a part of these calculations, we assumed that no coal was detrained from the top, flat portion of the coal load during transit. Because of this assumption, mass-loss calculations based on volume losses tended to ***underestimate*** actual material losses.

The photographic method of calculating, while general successful, encountered problems related to the changes in bulk densities of coal as it dries and drifts and inadequate measurements in the fronts and rears of cars where significant erosion and redeposition can occur during transit. In addition, the photographic method was very labor intensive. Consequently, another method was developed to estimate volume changes and evaluate redistribution of coal within a car. This method, called the Coal Car Load Profiling System (CCLPS), used three cameras to produce a digital contour map of the coal surface and calculate volume changes from mine to port within a given car. Recently, the CCLPS data gathering process has evolved into an infrared laser-based system which is smaller, faster, and does not require special lighting as did the three-camera technology.

Real-time Observations

To characterize the nature of fugitive dust emissions and develop an understanding of the wind erosion processes on coal cars during transit, an instrument package was designed to monitor a variety of environmental parameters in real time as the cars moved down the rail corridor. The instrument package, Rail Transport Emissions Profiling System (RTEPS) measured the following variables: wind speed, wind direction, rainfall, coal surface temperature, coal temperature and moisture at two different depths, fugitive emissions (using a real-time aerosol sensor, or RAS), air temperature, and relative humidity. All of these data were collected and stored in a data logger attached to RTEPS and were retrieved via a lap top computer at various locations along the corridor. A time-lapse video camera was also part of RTEPS to provide visual records of emission events.

Passive Collection

To directly sample detrained material in transit, passive collectors were designed and built to mount on the rear sill of test cars. The passive collectors were sampled a various stops along the rail corridor to help identify the dustiest portions of the trip.

Dust Suppression Techniques

Once is was determined how much coal was being lost during transit, several mitigation techniques were evaluated, including:

- water only (40 to 100 gallons/car, depending on the experiment);
- grooming ("rounding" of the load profile) only;
- water and compaction;
- surfactants only;
- surfactants plus binding agents;
- binding agents only; and
- tarped cars (used as control cars for various experiments).

Experiments were also conducted where the average train speeds were decreased, and where trips were run mostly at night to decrease emissions. While lower train speeds and coal surface temperatures produced less stress on the coal loads and therefore lower emissions, such operational constraints were neither sufficiently effective nor practical and therefore were not seriously considered as permanent mitigation techniques. In addition, several load profile modifications were used alone, and with the treatments listed above, to abate fugitive dust emissions. Initially, a "normal" profile had a trapezoidal cross-section as shown in Figure 1a. After it was shown that profile modification alone significantly reduced emissions, the "bread-loaf" or groomed profile became the norm (Figure 1b). Other grooming/loading options included loading the coal flat, at or below the car sill level, loading lower than normal, and reshaping the top of the load into the "bread-loaf" shape. For clarification, the following definitions are given for surface treatments.

Normal profile: for the first sixteen field trials, cars that had a trapezoidal cross-section (Figure 1a); for the last fourteen field trials, cars that had an arcuate or " bread-loaf" cross-section (Figure 1b).

Groomed profile: any car that had an arcuate cross-section, or was modified to eliminate angular or trapezoidal cross-section.

Untreated cars: cars that may or may not be groomed, but received no additional water spray, surfactants, nor chemical binders.

Treated cars: cars that may or may not be groomed, but did receive additional water spray and/or surfactants, and/or chemical binders.

RESULTS

Laboratory Evaluations

Using the relative dusting index generated from the SARTDX experiments, coals were ranked according to their dusting potential. The final overall rankings were based on combining three dusting parameters: 1) wind speed threshold (WST), or the lowest wind speed at which emissions were detected; 2) maximum real-time aerosol monitor (RAM) readings; and, 3) total integrated emissions (IE), the calculated area under the entire emissions curve.

Interestingly, when the overall dustiness rankings based on the above three parameters were compared to what the rankings would have been based only on moisture content and fines content, the rankings were found to be discordant. While it is assumed that moisture content and size consist do play a role in a coals' dusting potential, it is clear that other factors (e.g., coal chemistry, moisture migration through the coal, and angle of repose) can play an equally important or even dominant role in dusting during transit.

For the 19 different coals tested in the SARTDX experiments, the inherent coal moisture contents ranged from 2.8 to 11.4%. In order to test all coal samples under the same conditions, it was necessary to dry all samples to approximately 1.5% moisture content (± 0.5%). It is fully recognized that such drying procedures do not reflect actual field conditions, as moisture contents vary significantly from mine to mine. However, the drying process allowed for marked and consistent delineations between the different coals' dusting potential, which was the objective of the SARTDX experiments. Figures 2 a and b, below, show SARTDX wind tunnel plots for two coals. Coal # 1, (Figure 2a) displays a moderate tendency to dust, while Coal # 2 (Figure 2b) shows a much greater propensity to dust during transport. This is displayed in the upper parts of the graphs, along the "Mini-Ram" axis.

Field Studies

Scale Weight Changes

During the field trials, 317 cars were weighed. For the earlier field experiments, a normal profile for a fully loaded coal hopper was trapezoidal in cross-section, had a smooth flat top-surface, and was stacked approximately eighteen to twenty-four inches above the car sill. After taking moisture changes into account, the normally loaded, untreated cars lost an average of 0.36 tons (± 0.1 tons), n = 52. The range for the scale-weight losses was from 0 to 0.6 tons, and some cars actually showed a weight gain--due to water uptake during transport. The greater losses occurred during the most severe (hottest and driest) conditions in the summer months, when wind and train speed averages were highest compared to other field trials.

Those cars that were loaded at or below the sill appeared to loose less coal in most cases, compared to normally loaded and untreated loads, but this difference was not statistically significant. Furthermore, these loading techniques reduced the load capacity for each car by 10 to 15%. Since loading at or below the sill gave mixed dust control results and reduced the load capacity, this dust suppression strategy was abandoned.

For the most recent field trials, the normal load-out procedure was changed to a "bread loaf" profile. The change in profile produced a measurable reduction in the weight losses for the untreated cars, with an average of approximately 0.20 tons (± 0.1), down from the 0.36 tons for ungroomed cars. While load profile changes produced significant decreases in weight losses, further reduction in material losses (95 to 99% from untreated cars, based on passive collection) was achieved by applying surfactants and/or binding agents to the groomed profiles.

RTEPS Data

The RTEPS instrument package offered an independent and corroborative perspective of material losses compared to the scale weight changes and passive collection. RTEPS was not designed to quantify material losses, but to record in real time the intensity and frequency of dusting "events." We emphasize that the emissions are a relative measure (relative to no emissions), and do not represent material losses. There is a strong positive correlation between frequent, intense dusting events during the course of a trip and its scale weight changes and passive collection. Furthermore, the higher the average coal surface temperatures, wind speeds and train speeds, the more frequent and intense the dusting events became (Fig. 3). While riding behind the coal trains in the research caboose, it was clear that dusting increased when coal cars passed through tunnels, over trestles, and close to topographic interfaces. RTEPS data also showed that emissions were most frequent during accelerations between fifteen and thirty miles per hour. The most frequent and intense emissions occurred when the study trains passed other trains moving in the opposite direction at track speeds.

Load-top Volume Changes

The original photographic method for estimating volume changes produced material loss estimates of 0.11 to 0.76 tons, with an average of 0.31 tons (n = 31). For these same cars, scale weight losses averaged 0.36 tons, thus providing some credence to the claim that the photographic method underestimates material losses. An example of "before" and "after" transects are shown in Figure 4. The photographic method also laid the foundation for an automated volume-change detection system such as CCLPS. As CCLPS becomes further developed, we hope to obtain more and more reliable results from our volume/mass-loss calculations.

Trip Stress Index (TSI)

In order to compare the stresses from trip to trip, an index was devised from information collected with RTEPS. Air temperature, coal surface temperature, and wind speed were combined to arrive at a Trip Stress Index (TSI), allowing direct comparison of the stresses from each trip. A relationship between passive collection and TSI was revealed through data analyses and is discussed below.

Passive Collection

Over the course of the thirty field trials, a total of 360 passive collector samples have been taken. The combination of profile modification and chemical sprays has resulted in a 95 to 99% reduction in coal losses compared to normal trapezoidal load profiles according to passive collection data. Statistical analyses of passive collection show that treated cars can be distinguished from untreated cars with a 99.9% confidence level. Table 1 depicts the average passive collection over all trips for untreated versus treated cars. The 153 passive collector samples not shown were either collected during "experimental" treatments, or there was no direct comparison available for treated versus untreated cars for a given experiment.

There appears to be no useful correlation between scale weight changes and passive collection on a car-by-car basis, likely due to the inherent scale inaccuracies and moisture content variations. This is another reason not to rely on the scale weight changes alone for material loss estimates, but instead, to apply independent loss estimates techniques. However, a clear relationship between passive collection and TSI is revealed in Figure 5. This relationship appears to be exponential. On the other hand, the data suggest that there is some threshold above which passive collection (i.e., fugitive emissions) significantly increases.

Surface Treatment Evaluations

As previously mentioned in the "Methodology, Surface treatments" section, a variety of surface treatments were tested during the study for their dust suppression capabilities. Using untreated cars as the reference for judging the success of treatments, results from RTEPS show that water-only treatments, whether sprayed on at the mines or en route, suppressed fugitive emissions for a maximum of only two to three hours under stressful conditions during a thirty-six to seventy-two hour trip. In fact, untreated surfaces actually emitted less dust than water-only treated cars under certain conditions (e.g. freezing temperatures). This was the case for both groomed and ungroomed cars. Grooming alone reduced passive collection and scale weight losses from an average of 0.36 tons to 0.20 tons during the most stressful trips. When profile grooming was combined with chemical treatments, even greater reduction in fugitive emissions was realized, up to 95% over untreated cars.

CONCLUSIONS

A total of thirty field trials have been conducted to date for the NSRES.

Analyses and stratification of a 360,000-car database yielded a standard deviation of about 6 tons in dump weights, masking any meaningful signal for weight losses for the NSRES.

Material losses based on scale weight changes for ungroomed, untreated cars averaged about 0.36 tons/car under high stress trip conditions.

Material losses based on scale weight changes for groomed, untreated averaged about 0.20 tons/car in the high stress trip conditions.

Intensity and frequency of emissions are greatest when the train is accelerating between 15 and 30 miles per hour, and when passing on-coming trains.

Increased fugitive emission events are associated with tunnels, trestles, and topographic interfaces.

The relationship between the Trip Stress Index and passive collection indicated that there is a stress threshold above which fugitive emissions significantly increase.

Based on passive collection, material losses from groomed, treated cars were reduced by up to 95% over untreated and ungroomed cars.

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Table 1. Passive Collection for Untreated Versus Treated Cars

UNTREATED CARS AVERAGE (g)	TREATED CARS AVERAGE (g)
n = 113	n = 94
131	5

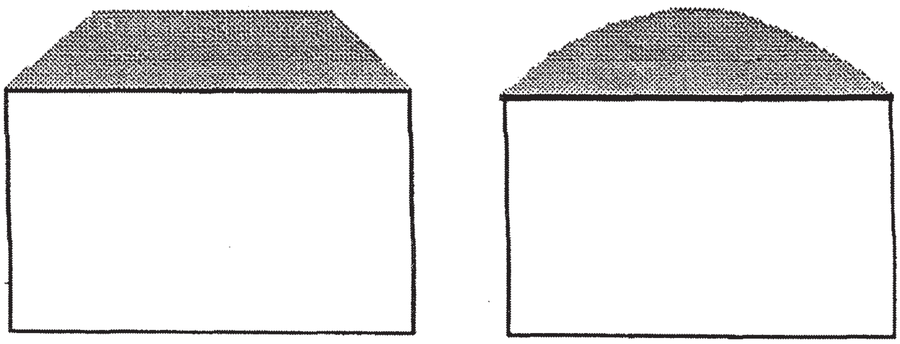

Figure 1a (left) and 1b (right). Cross Sections of Coal Hoppers with Trapezoidal Profiles (1a) and Rounded Profiles (1b)

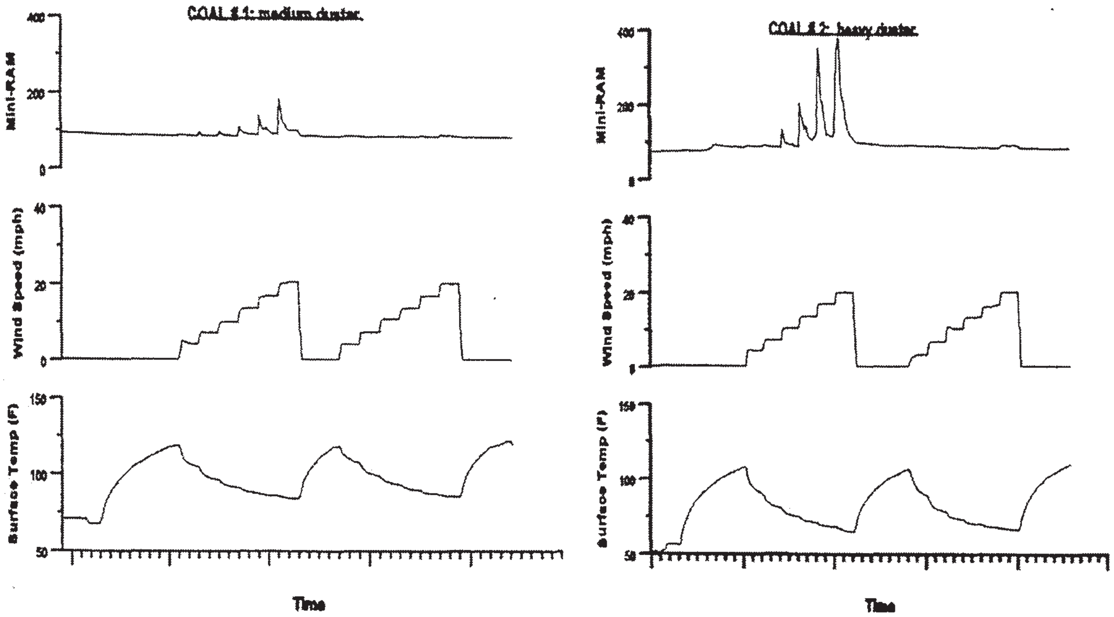

Figure 2a (left) and 2b (right). Graphical Difference Between "Medium" and "Heavy" Dusty Coals According to SARTDX Procedures

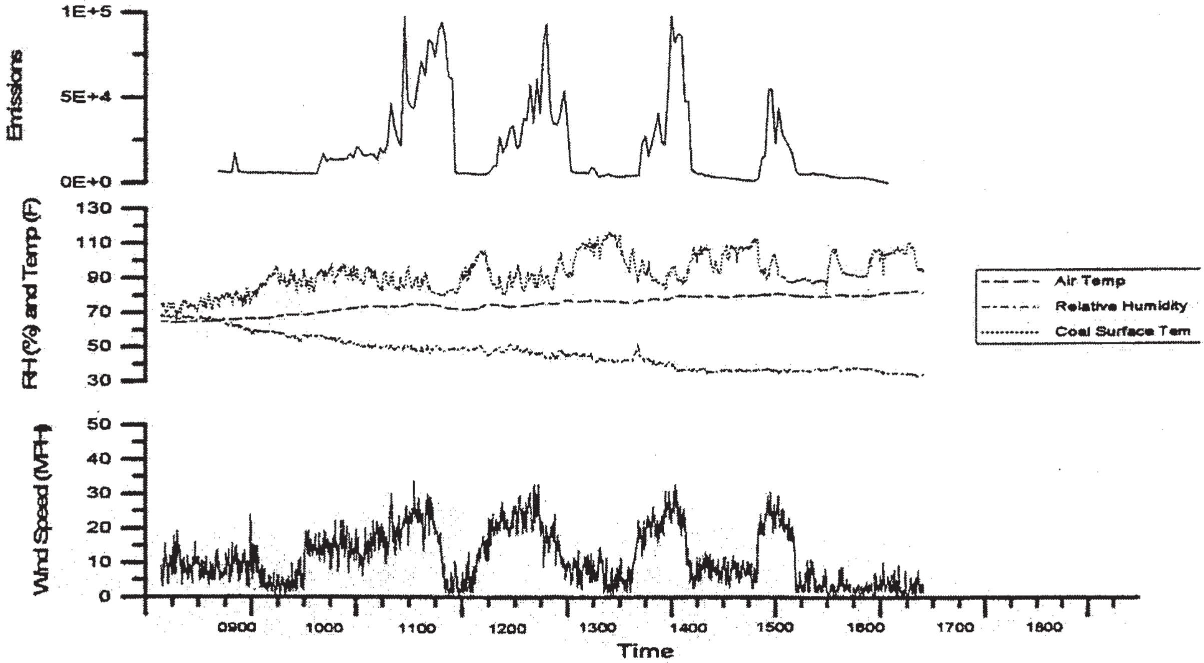

Figure 3. A Typical RTEPS Trip Profile Showing the Correlation Among Emissions, Coal Surface Temperature, and Wind Speed

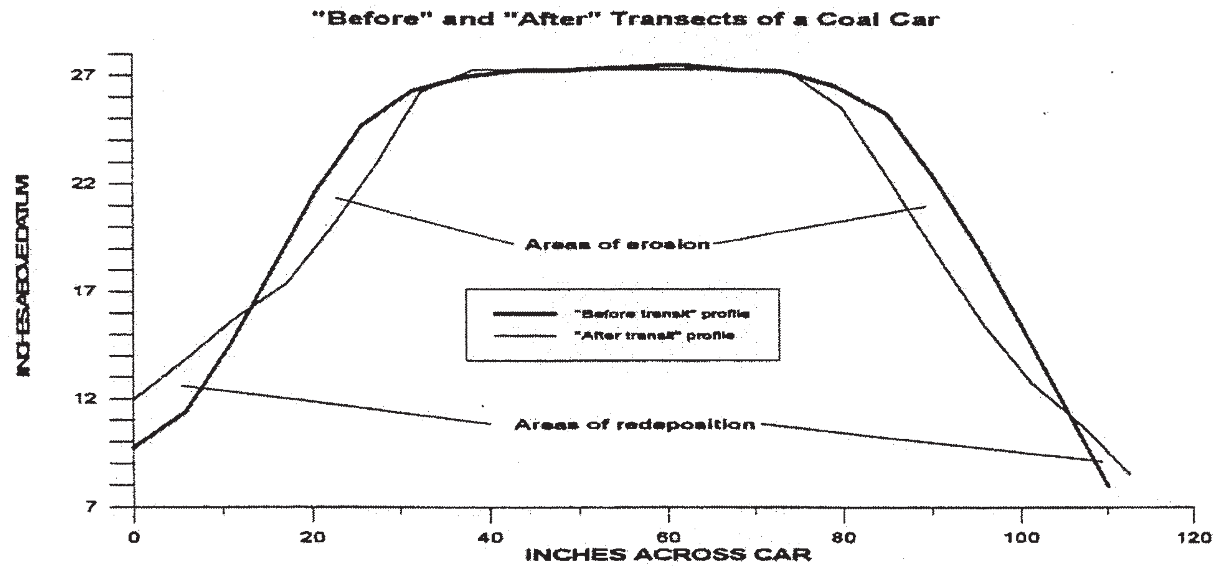

Figure 4. An Example of a Photographic Transect Across an Untreated Car Showing Areas of Erosion and Deposition

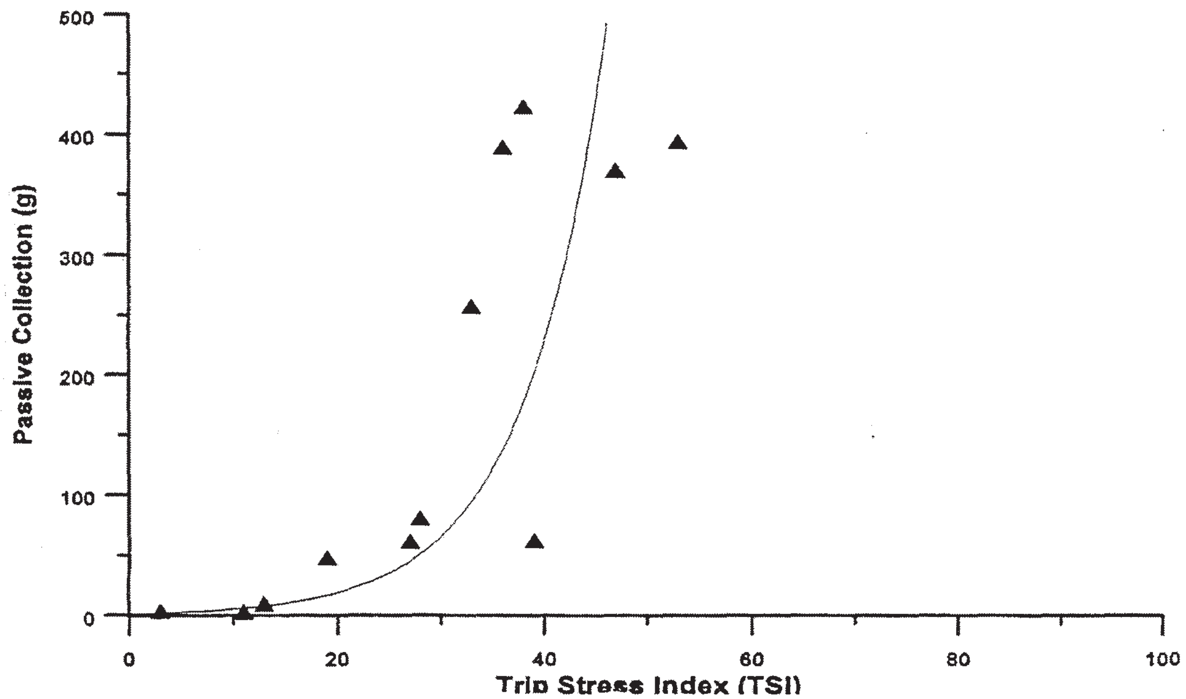

Figure 5. Trip Stress Index Versus Passive Collection