Processing of Spent Mushroom Substrate

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INTRODUCTION

Spent Mushroom Substrate (SMS) is often disposed of by spreading on fields, processing in windrows or selling directly to nurseries or landscapers. It has also been used as a soil amendment for growing horticultural plants or crops (Lohr and Coffey, 1987; Chong and Rinker, 1994; White, 1975). SMS processing has the potential to generate odors, particularly if the piles of substrate are not handled carefully (Miller and Macauley, 1988, 1989). Anaerobic zones can form in the substrate windrows, generating compounds that produce foul odors in Phase I substrate preparation (Derikx, *et al.* 1990, 1991). Frequent turning may reduce the production of these compounds, but may not be enough to eliminate the odors. Labor and equipment required for frequent turning have a financial cost.

Forced aeration is increasing in fresh mushroom substrate preparation (Phase I) operations (Miller 1993, 1997). Several Phase I operations in Europe, Canada and the United States have already built these aerated-floor "bunkers," are in the process of building them, or are in the design and planning phase. These bunkers have been shown to reduce odors in Phase I, and research projects have been initiated to study the proper management of these facilities.

It is evident that as more research is performed on the properties and uses of SMS, the more added product value that SMS provides is discovered. SMS has been used in growing media and as a soil amendment for years due to its structural properties and fertilizer value. SMS has also been found to have disease-suppressing qualities (Romaine and Holcomb, 2001). Lastly, it can be a source of fertilizer when used in growing media.

The Pennsylvania State University, Monell Chemical Senses Center and Therion, Inc. have been collaborating to investigate the use of aeration for SMS processing. Specific objectives were to: (1) design an aerated floor bunker for maintaining aerobic conditions of SMS during processing, (2) assess odors from aerated SMS vs. windrow SMS using human panels and quantitative means, and (3) compare the processing durations between aerated SMS and windrow SMS.

Aerated Floor Bunker

Anaerobic microbial activity produces the strongest odors during SMS processing. Borrowing the idea from Phase I preparation and other types of composting, an aerated floor vessel was built for reducing anaerobic activity, and consequently, the odors produced.

The portable aerated bunker system used for processing SMS was a modified 8' wide x 14' long hook lift container (Figure 1). The box was divided into a 9' x 8' aerated floor processing section and a 5' x 8' enclosed instrument room.

Air was supplied to the processing section by a blower located in the instrument room. Twelve 2' x 2' aeration blocks provided the air supply plenum and distributed the air at the bottom of the SMS. Controls and instrumentation for operating the system and taking air samples were located in the instrument room.

Temperature, Oxygen Measurements and Aeration Control

SMS temperatures were monitored by thermocouples connected to a computer through a data acquisition card. The thermocouples were located at 12", 24", 36" and 48" on a pole centered in the SMS chamber. These locations were chosen to provide a vertical temperature profile through the substrate. Temperatures were measured once per day in the windrow at four locations using a thermocouple meter.

Oxygen levels were measured using a portable oxygen meter. Four holes located on the vessel side walls allowed a probe to be inserted approximately 2.5 ft. into the SMS. The holes were plugged when oxygen sampling was completed. Oxygen levels in the windrow were sampled daily using the same meter, also approximately 2.5 ft. into the SMS.

Aeration was provided by the blower located in the instrument room. The SMS aeration scheme was designed to maintain temperatures between 122 and 131°F for optimal processing and oxygen levels. If the temperature at the 36" level was less than 122°F, the SMS was aerated for three minutes per half hour. If the temperature was above 131°F, the SMS was aerated continuously until the temperature dropped below 131°F. When the SMS was first loaded into the vessel, the microbio-

Figure 1: Aerated floor vessel, showing the aeration chamber. Instrument room is in the rear of the vessel.

logical organisms had begun the decomposition activity but temperatures of the SMS were usually below 95°F. Aerating at a regular interval helps to increase the activity and therefore the temperatures. If the SMS temperature gets above 140°F, activity begins to slow down and the material will not be properly processed. Several trials were made during Summer and Fall of 2000, primarily to work out any problems with the instrumentation and control schemes, as well as some preliminary temperature comparisons.

Odor Assessment – Human Panel

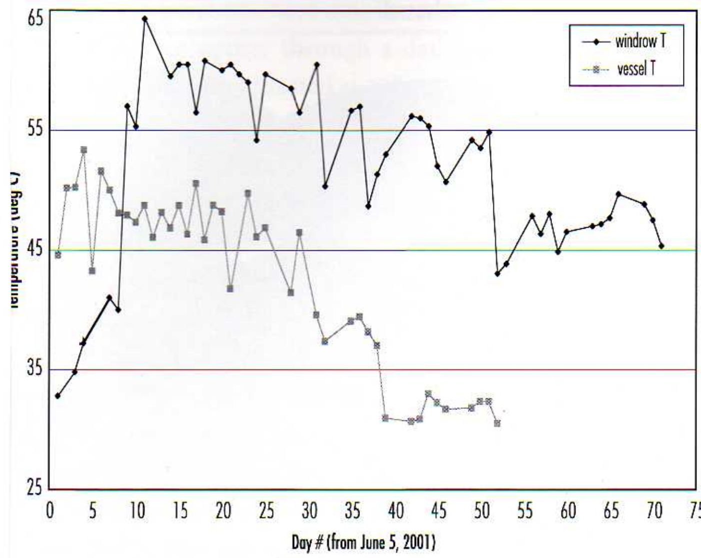
Odors were assessed by a human panel weekly or bi-weekly, using the "Labeled Magnitude Scale" for intensity, which is a scale from 0 (no odor) to ~100 (strongest intensity imaginable) (Green and Flammer, 1989; Green *et al.* 1996). Each panelist also rates odor pleasantness on a scale of –11 (extremely unpleasant) to +11 (extremely pleasant).

The panelists sampled the treatments in two ways. First, a perforated stainless steel probe was inserted into the SMS. Air was drawn out from the SMS through a tube connected to the probe and a pump. Each panelist sniffed the end of the tube. This sample was called "pumped." The panelists also assessed odors, using the same scales, from the plumes of the piles while they were being turned and from the vessel through the vent in the back while the blower was running. This sample was called "plume."

Odor Assessment – Quantitative

Odor complaints regarding the processing of SMS appear to involve the release of hydrogen sulfide and other malodorous compounds. Therefore, air samples were also analyzed by gas chromatography/flame photometric detection (GC/FPD) on a weekly or bi-weekly basis. Samples for GC/FPD were obtained

Figure 2: Average vessel and windrow temperatures from Jun. 5–Aug. 15, 2001



using the same approach as was used for the olfactometric assessment (pump and plume). Two samples from each treatment were obtained in this manner. The gas sample bags were shipped to Monell Chemical Senses Center via overnight express and analyzed on the day following sample collection.

RESULTS

The SMS was shipped directly from commercial mushroom production rooms, without any further composting or weathering. The SMS was divided into the vessel and into the windrow, approximately 14.0yd^3 each. The SMS in the windrow was turned once per week while the odor assessments were taking place, beginning eight days after the windrow was built. The SMS in the vessel was not turned. Water was added to the vessel and windrows at the start of the processing period since the shipped material was rather dry. No additional water was added to the vessel treatment. The windrows received only natural precipitation after the initial watering.

Temperature and Oxygen

The average aerated floor vessel and windrow temperatures are shown in Figure 2. The windrow temperature remained above 122°F for most of the processing period, even after about 10 weeks. The vessel temperatures dropped earlier, about 39 days after loading. It appears that aeration allowed the substrate biological activity to finish off in less than six weeks. Commercial operations that process SMS have indicated that their windrows require 10 weeks of processing before temperatures drop.

Oxygen levels for the windrow and vessel are shown in Figure 3. These are shown only after day 20 due to problems with the

Figure 3: Oxygen levels for vessel and windrow.

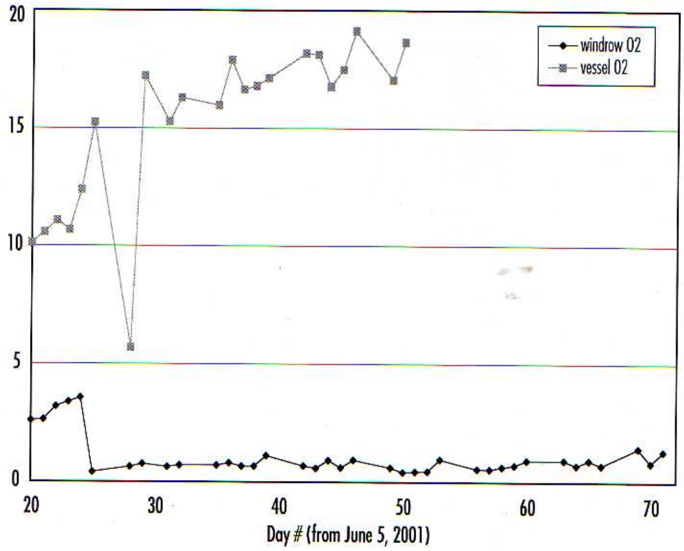
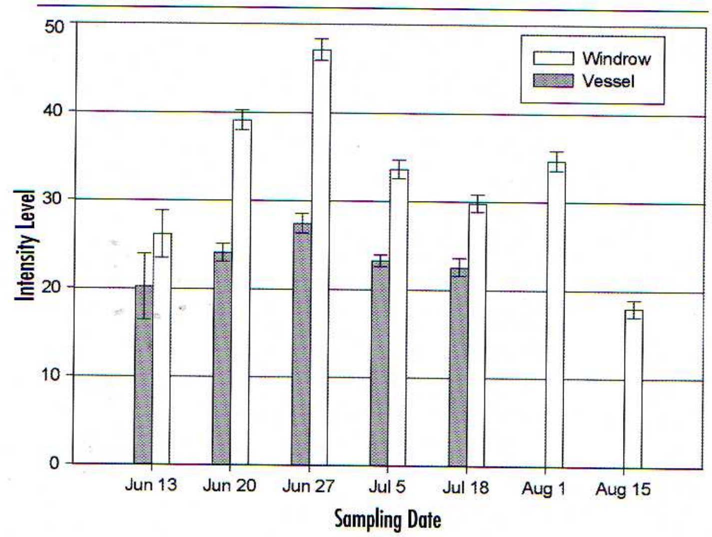


Figure 4: Intensity ratings for samples pumped from SMS. Error bars show standard error of the mean.



oxygen meter prior to that date. It is clear that the oxygen level in the windrow is consistently in the anaerobic region, below four percent by day 20 and remaining below one percent for most of the remaining time after day 25. Weekly turnings do little to help with oxygen content; in fact turning the windrows serves only to mix the material rather than supply oxygen. The vessel, on the other hand, maintained oxygen levels above 10 percent except for short periods of time on days 14, 15, and 28. After the fourth week, oxygen levels were always above 15 percent.

Human odor assessment

Human panel intensity ratings for samples pumped from the

Figure 5: Pleasantness ratings for samples pumped from SMS. Error bars show std. error of the mean.

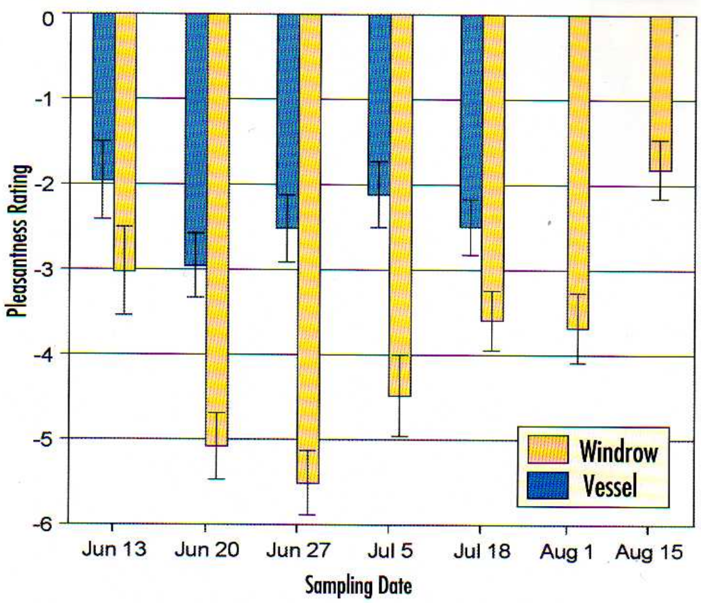
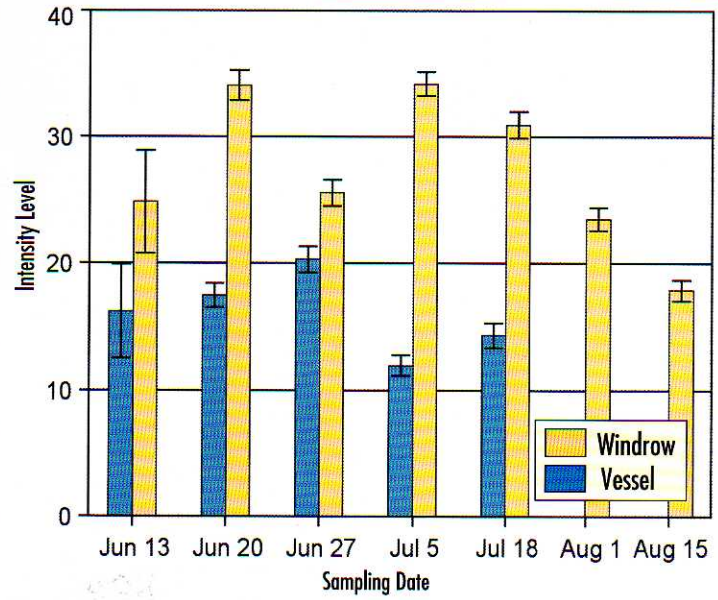
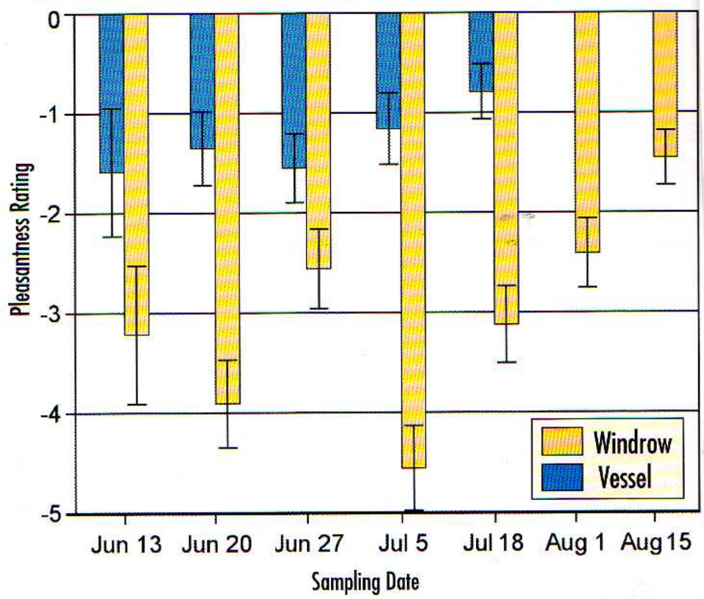


Figure 6: Intensity ratings for samples collected from plumes. Error bars show std. error of the mean.



vessel and windrow SMS are shown in Figure 4. Statistical analysis showed that the windrow odor intensity was significantly higher than vessel intensity across all weeks. Windrow intensity ratings were always significantly higher on each sample date than the vessel intensities, with a peak rating of 47 on June 27. The highest vessel intensity was 27.4, on the same day. No intensities were measured for the vessel on August 1 and 15 because the SMS had finished processing in the vessel and was

Figure 7: Pleasantness ratings of samples collected from SMS plumes. Error bars show std. error of the mean.



removed before August 1. Pleasantness ratings for samples pumped from the windrow and vessel are shown in Figure 5. Again, statistical analysis showed that the windrow samples were consistently more unpleasant than the vessel. The peak windrow unpleasantness of –5.5 occurred on June 27. The peak unpleasantness for the vessel was measured to be –3.0 on the same date. Intensity ratings for the plumes are shown in Figure 6. Statistical analysis showed that the plume intensities were significantly higher for the windrow than for the vessel, with a peak of 34 on June 20 and July 5. Plume unpleasantness ratings are shown in Figure 7. Once again, the windrow plume was significantly more unpleasant and peaked on July 5 at –4.6. The peak unpleasantness for the vessel plume was measured on June 13 and June 27 at –1.6.

It is clear from the analysis that aeration reduced odors, in terms of both intensity and unpleasantness. The peak windrow values of intensity and unpleasantness were close to twice tha of the vessel in many instances and almost three times highe for the windrow plume unpleasantness. Pleasantness values o –5 would be considered moderately to strongly unpleasant while values of –2 would be considered mildly unpleasan Some panelists even considered the vessel plume to be mildl pleasant on some sampling dates.

Temperature is one way to determine the reduction i biological activity within the SMS, either in the windrow or th vessel. However, another way is to assess the odors. After th vessel material was assumed to be finished after six weeks c processing, the SMS was removed from the vessel and placed i a separate windrow. A formal odor assessment was not pe

Figure 8: H_2S levels for samples pumped from SMS.

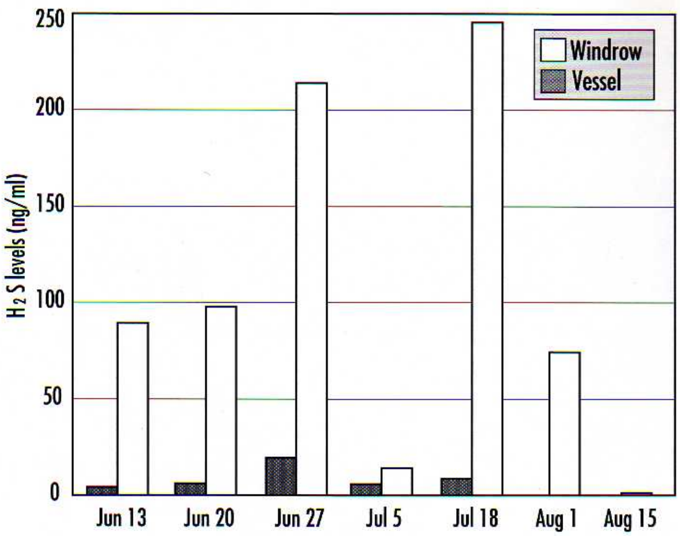
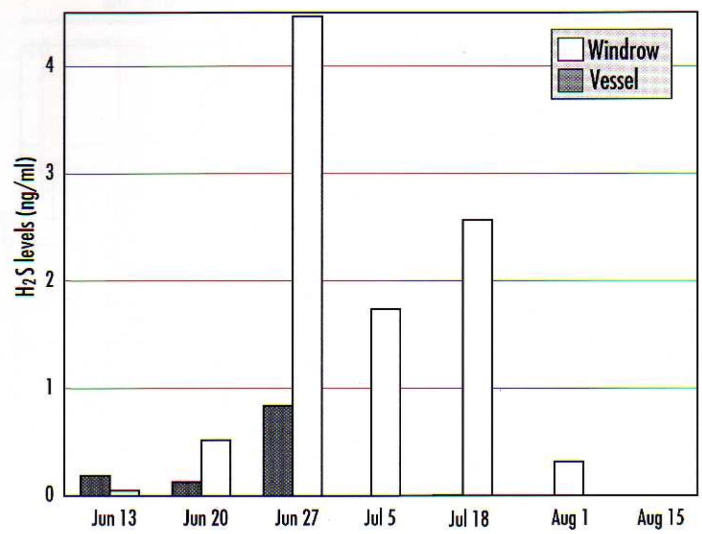


Figure 9: H_2S levels from plume samples

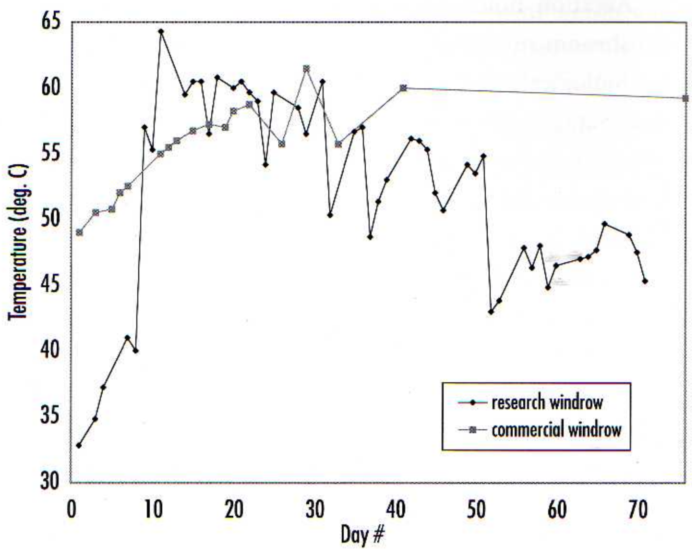


formed on the vessel material at this point, but a sample was pumped from the vessel windrow one week after it had been removed from the vessel. The investigators olfactometrically evaluated this air stream and found only a musty, earthy smell rather than the sulfurous odors one would expect if the material was still biologically active.

Quantitative Odor assessment

Hydrogen sulfide levels of samples pumped from the windrow and vessel are shown in Figure 8. For most of the trial, H_2S levels were considerably higher in the windrow than in the vessel. The peak windrow level was 245 ng/ml on July 18, while the peak value for the vessel was 19.3 ng/ml on June 27, almost 13 times lower.

Figure 10: Commercial and research project windrow temperatures.



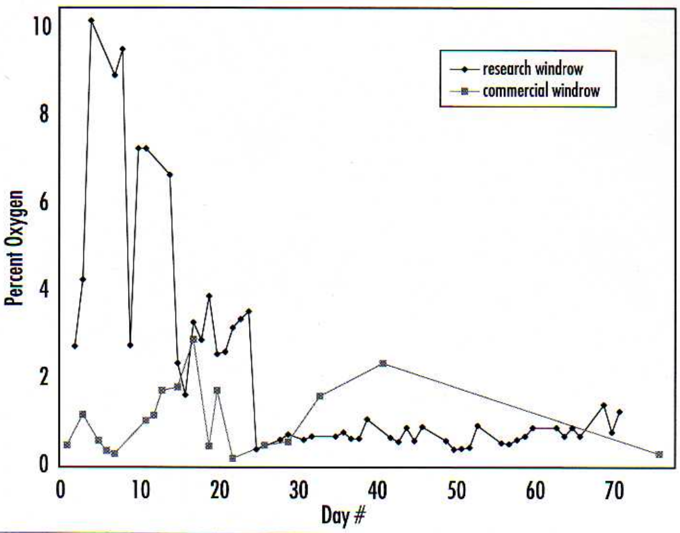
Hydrogen sulfide levels of samples taken from the windrow and vessel plumes are shown in Figure 9. The overall levels detected in the plume were almost two orders of magnitude lower than those found in the pumped samples (note y-axis scale). Even so, the H_2S concentration in the vessel plume was much lower than that of the windrow plume.

COMPARISON WITH OBSERVATIONS FROM A COMMERCIAL OPERATION

Windrow oxygen levels and temperatures were also measured at a commercial spent mushroom substrate processing operation during the same time period. These observations were compared with the research observations to determine if the size of the research windrows would provide similar results to the larger commercial-scale windrows. The windrows used in this research were approximately 4.5 ft. high and 6.5 ft wide. A commercial windrow is typically 6.5 ft. and 9.8 ft wide. Temperatures of the research project windrow from Summer 2001 are plotted with commercial windrow temperatures sampled at about the same time of the year (within a couple of days) in Figure 10, and oxygen levels are plotted in Figure 11. It can be seen from these figures that the temperatures and oxygen levels of both are relatively close, indicating the research size windrow is representative of the commercial size windrow.

Anecdotal suggestions imply that the so-called "chimney effect," or the drawing of air into the material through convective forces, would supply sufficient oxygen levels within the windrow to maintain aerobic conditions. Results from both the research trials and the commercial operation show that this is not the case, and that oxygen levels drop very rapidly after the windrows are turned each week.

Figure 11: Commercial and research project windrow oxygen level.



CONCLUSIONS

Aeration holds great promise for reducing odors from mushroom substrate processing as well as reducing the time for biological activity within the substrate to come to completion. Samples pumped from the piles generally had higher odor intensity and were less pleasant than samples taken from the plumes, but the vessel showed less odor intensity and was more pleasant than the windrow in almost all samples. Quantitative assessment helped to confirm that less odorous compounds were produced in the aerated material. In particular, hydrogen sulfide concentrations in the vessel SMS were as much as two orders of magnitude less than the concentrations found in the windrow SMS. Measurements of temperature and oxygen from a commercial SMS processing operation showed that the experimental results were representative of larger scale processing facilities.

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