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INTEGRATED SYSTEM AND METHODOLOGY FOR BACK-PRESSURE TESTING CATALYST-PACKED TUBES IN TUBULAR REACTOR VESSELS

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AN OVERVIEW OF BLOWDOWN AND BACK-PRESSURE TESTING

A variety of commercially-important chemicals is produced by passing gaseous feedstocks through the catalyst-packed tubes of tubular reactors. The extent of catalytic conversion in each tube (and thus product concentration) is proportional to the uniformity of the reactor's tube-packing density. When the useful life of the catalyst comes into question, a catalyst change-out occurs, a dust removal operation or blowdown is conducted and packing density uniformity is assessed. Product quality is thus ensured by (a) injecting a constant-flow test-gas stream into each tube, (b) measuring the back-pressure, (c) evaluating the resultant pressure-drop (proportional to packing density), (d) adjusting tube loadings to improve the packing density uniformity, (e) re-measuring back-pressures, and (f) repeating as required until the pressure-drops and the implied packing densities are acceptably uniform. The ultimate goals are to measure the back-pressure on each tube, manage the data efficiently, and assure reactor tube packing density uniformity as quickly as possible.

Until recently, management of the process has not had the rapid, sophisticated analytical decision-making tools needed for optimally evaluating and adjusting the packing density for maximum quality and minimal downtime.

AN INTRODUCTION TO The Tube*Master*™ System

The Tube*Master*™ System is a new system (patent pending) for high speed blowdown and back-pressure testing of reactors tubes, available by lease and license. See Figure 1. It is designed to solve the speed, accuracy, data management, and many other quality problems associated with current systems and procedures. Major components include an Automatic Blowdown System (ABS) and Tube Test Device (TTD), a wand containing ten tube-seal test gas injectors. The system also includes a real time graphical display an umbilical for use on single tubes; a power and data module; a host computer with special software; and either wire or wireless communication between wand and computer.

A full back-pressure test is done by repeatedly (1) inserting the TTD in a bank of ten tubes, (2) pushing the start button (the test and data collection is then done automatically), and (3) moving over ten tubes in the row and repeating. Testing is quick (1,000 tubes/hour); accurate (within 0.1 inch of water), and efficient (via computerized data management, analytical tools, and a GUI to show test status). The following section provides details on Tube*Master*™ solutions to common problems.

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Tube*Master*™ SYSTEM SOLUTIONS AND ENHANCEMENTS

A. <u>Major Speed Advances in Blowdown and Pressure Test Procedures</u>. A primary limitation of present blow-down and back-pressure test systems is that they use a single air/gas-circuit wand for each process, permitting blow-down and test on only one tube-at-a-time per person. Testing a 15,000 tube reactor this way requires using many single-tube wands, large crew sizes (typically 8-20 people), and operations over one or more shifts (typically 12-30 hours). Since The Tube*Master*™ System can blow-down or test and record data on ten tubes at once, a crew of four can complete the task in four hours.

B. <u>Advantages in Difficult Reactor Working Environments</u>. A reactor head space is cramped, dusty, noisy, permit-required confined space which requires special safety equipment and procedures, including rescue, and makes verbal communication difficult. By greatly reducing crew size and work time, adding a visual Tube Capping Guide, and providing visual rather than audible communication, The Tube*Master*™ System significantly reduces safety problems and data management errors.

C. <u>Novel Interface for Reactor/Tube Configurations</u>. Common blowdown and test procedures require use of a foot peg to hold single tube wands in place against pressure and there many gas leakage problems because of multiple catalyst tube diameters and difficult interfaces with protruding tubes, irregularities, and poor weldment. The Tube*Master*™ System eliminates these problems by providing an assortment of conformable gas-injector seals which lock in tubes and prevent leakage.

D. <u>Measurement Advances</u>. Common back-pressure measurement systems have difficulty in maintaining the required constant flow; achieving accuracy and calibration over long periods of time in a changing temperature and pressure environment; and protecting the pressure sensor from damage when encountering a clogged or plugged tube.

The Tube*Master*™ System uses interchangeable needle valves, sonic nozzles, orfice plates, and precision orifices to achieve constant flow in a variety of reactors; an advanced technology sensor for accuracy within 0.1 inch of water; a custom calibration system which maintains accuracy in variable environments; and built-in protection against sensor overload.

E. <u>Computer Control over Complex Test Sequence and Operations</u>. It is very difficult using common blowdown and test procedures to manually keep track of each tube location, the test sequence, and the location of missed or plugged tubes. But in The Tube*Master*™ System, the blowdown and pressure test sequence and tube tracking are computer controlled and automated, saving valuable time and minimizing errors.

F. Electronic Job-Setup Documentation. Common systems and procedures are so complicated that they result in poor documentation of the reactor location, i.d., and configuration; number of tubes in each row; tube diameter and pitch; location of tube supports and thermocouples, loading zones; outages, the tube loading methods used, test operator names, wand i.d. numbers, calibrations, data conversion factors, and economic/cost data. Tube*Master*™ handles as much (or more) data which is computerized and organized into an electronic "Reactor Setup File" and a "Job Set-up File." All data are electronically stored for later retrieval, inspection, analysis, evaluation, or use at any time.

G. Improved Approach to Pass-Fail Criterion and Tube Sampling. Common manual test procedures have trouble determining, in real time, a rational pass-fail criterion or '"test spec", and which tubes fall outside it. They are too slow determining this by 100% testing and lack guidance on using absolute pressure criteria (which determines product quality) or on doing proper statistical sampling. The Tube*Master*™ System is amenable to absolute pressure criteria; provides statistical sampling guidelines and true random tube selection for statistical validity (see Figure 2); provides operator advice on the number of tubes which can be corrected and retested within a certain time period; and, when desired, can do 100% testing in the time required for common methods to do sampling only.

H. Advances in Data Collection, Documentation, and Display. Common, manual methods can scarcely cope with the huge volumes of data resulting from blowdown and test operations. It is necessary to account for special tubes, like plugged, thermocouple, and support tubes; to distinguish data from many vertical zones in each tube (all catalyst, inert carrier, or mixed); and to compile a list of failed tubes, by rows and tube number, through perhaps several retestings. But this is a simple, natural application for the computerized Tube*Master*™ System with its GUI and List-to-Fix™. It can, for example, display the location and status, and results for each tube, for each zone, and for any event or stage of the testing process (post-run, post clean, post fill, corrections only, and post-fill with corrections).

I. Electronic Data Tracking and Logging. Common approaches to blowdown and back-pressure testing and retesting face especially difficult problems for manual methods of tracking and keeping up with all the data collected; recording these and the many other data needed to develop a wider understanding of reactor status; and transmitting them to a reliable record or database, tasks that are quick and easy with The Tube*Master*™ System's computerized approach. Each tube location is automatically and electronically registered to an accuracy of 0.1 inch, and is time/date stamped; wands and operators are recorded and matched with data; and all data are routed to both the on-wand GUI (for immediate operator feedback) and an immediately available database (for archival).

J. Electronic Management of Large Data Arrays. The data management and formatting problem for manual, and even simple computer spreadsheet approaches, are inherently tedious and error prone, especially for reactors as large as 35,000 tubes but are a natural function for the Tube*Master*™ System's computerized data logging, recording, analytical, and reporting features.

K. Electronic Data Storage and Archival. Every project including blowdown (if required) and back-pressure testing on tubular rectors may be seen as a very important opportunity to save a vast amount of data for possible future analysis. This requires high quality documentation, storage, and retrieval of large data arrays. Manually sorting through hard copy records assembled from manual data pose an intimidating obstacle to further research, but The Tube*Master*™ System stores it all in the Reactor Summary and Data Summary Files which provide, on the spot, comma-separated files which are directly importable to Excel or other spreadsheet or statistical analysis programs.

L. Built-in and Host Computer Data Analysis. Ordinary manual tube-testing approaches have not anticipated the need or desire for appreciable later analysis and so have not recorded, coded, and formatted data for ready retrieval and computer analysis or comparison across many years of testing on multiple reactors. The Tube*Master*™ System has many analytical programs built-in. Its host computer, for example, can do many statistical comparisons and significance tests of differences between tubes, tube-testers, zones, loading methods, sister reactors, or present and previous turn-arounds.

M. Management Oriented Data Interpretation. Those responsible for reactor operations need an enhanced ability to make management decisions based upon large arrays of tube test data. Manually compiled data and later remote computer analysis are not up to the task. The TubeMaster™ System is specifically designed for management decision-making and provides programs for statistical, product quality, and economic decisions regarding such items as minimal downtime, best tube-loading methods, and improved reactor design.

N. Illustrations of Post-Run Statistical Analysis. In one example analysis, results were analyzed for two 18,000 tube formaldehyde reactors. Results showed that:

- The mean back pressures differ by more than 25%.
- The standard deviation of hand-loaded tubes in one reactor was nearly twice what it was in the other reactor, showing that hand-loading produced much more spread (a much less uniform distribution of tube loading) than did box loading.
- Both distributions looked like normal distributions (Figure 3), but chi-square tests (Figure 4) verified that box-loading produced distributions which were much closer to normal.
- Z-tests showed that the differences between mean pressures of the two reactors were statistically significant, and that hand loading produced significantly higher densities than did box loading.
- A kurtosis test verified that hand loading produced more peaked distributions (desirable) than did box loading (more nearly normal). See also Figure 4.

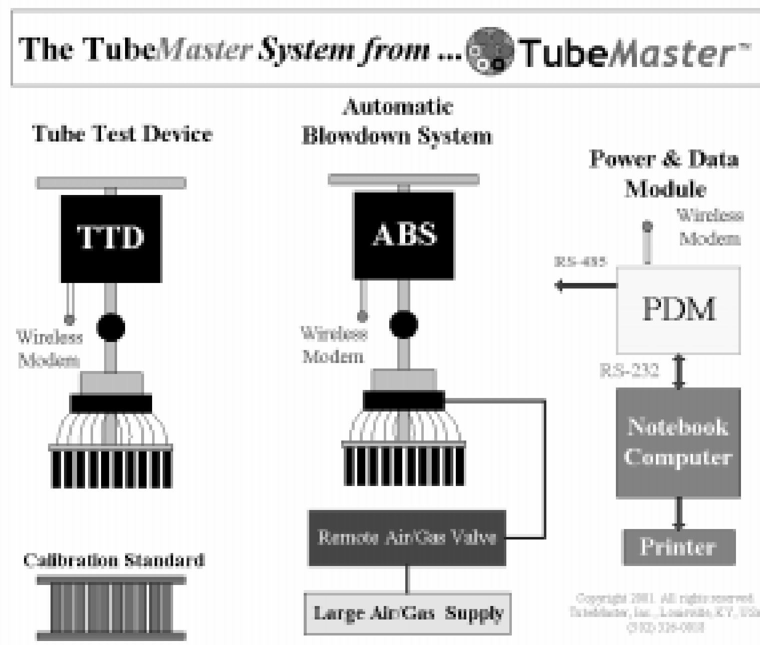


Figure 1. The Tube*Master*™ System

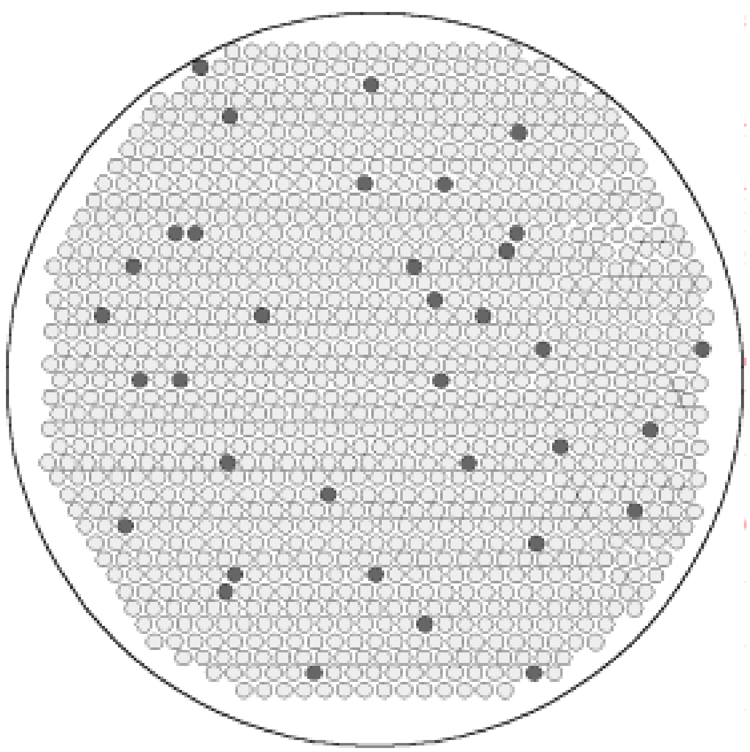
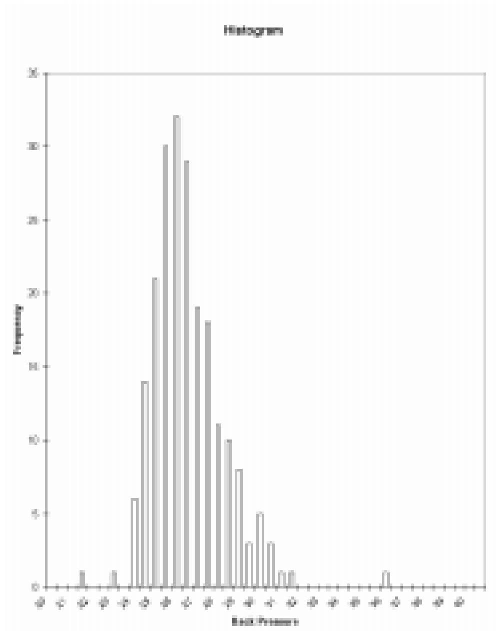
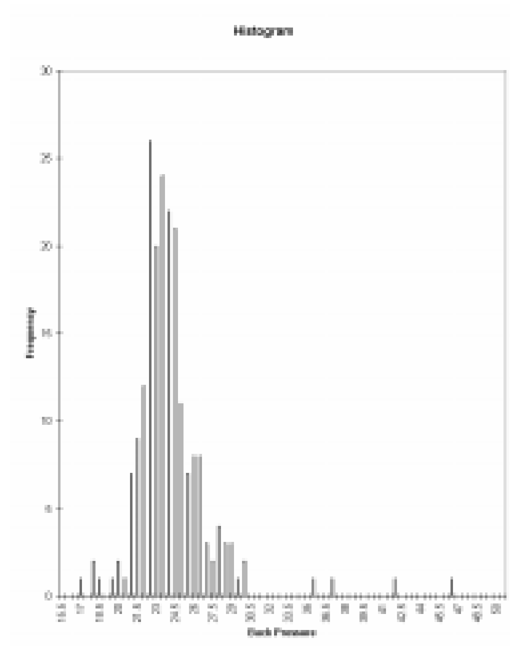


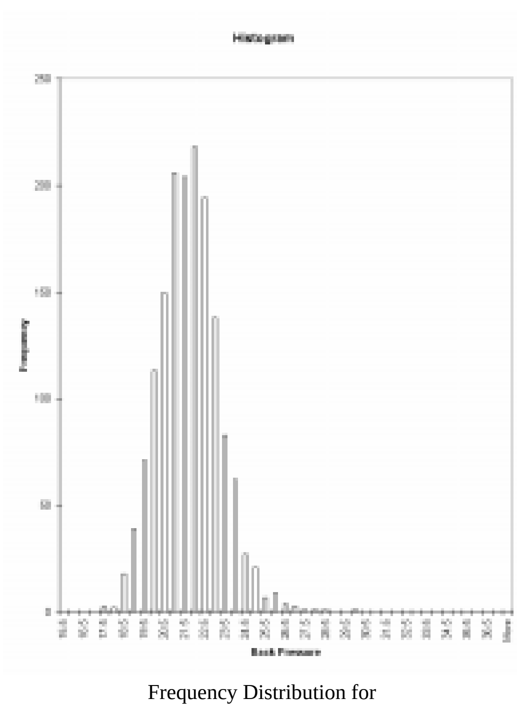
Figure 2. Random Sample Tube Locations as Shown on the TubeMaster™ System GUI



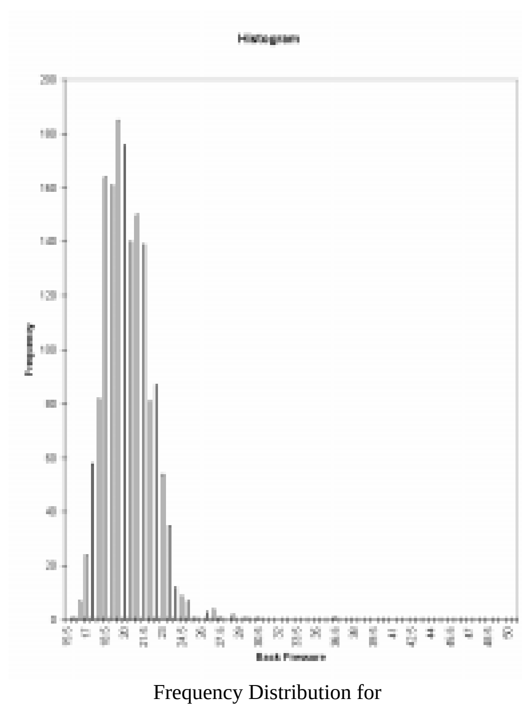
Frequency Distribution for
Hand Loading in Reactor 1



Frequency Distribution for
Hand Loading in Reactor 2

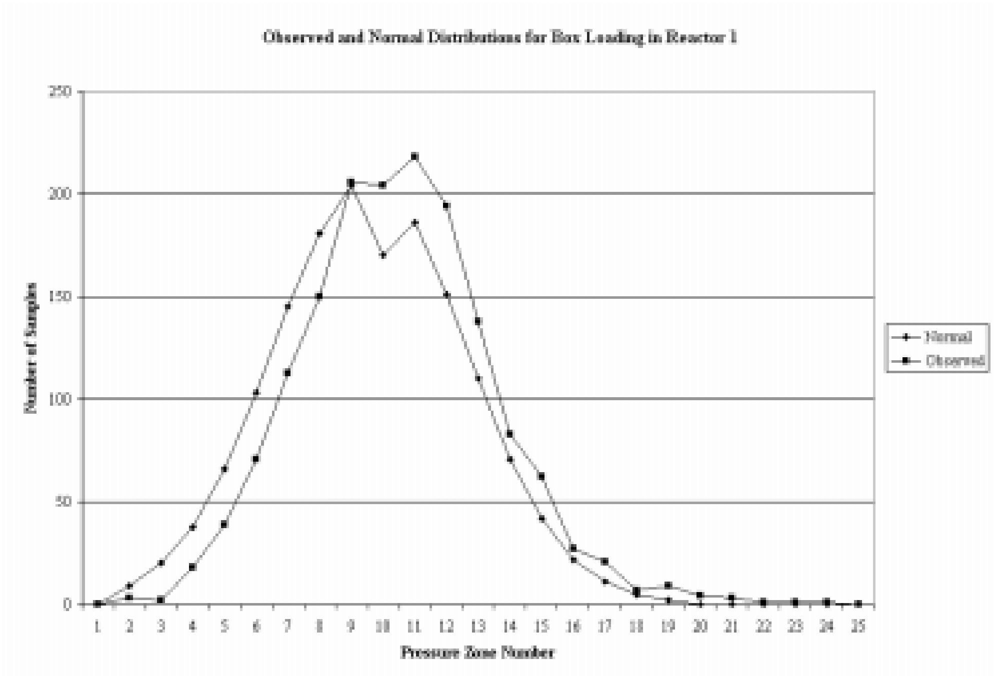


Frequency Distribution for
Box-Loading in Reactor 1



Frequency Distribution for
Box-Loading in Reactor 2

Figure3. Back-Pressure Test Distributions for Two 18,000-Tube Formaldehyde Reactors Containing 88% of Tubes Box-Loaded and 12% of Tubes Hand-Loaded (four histograms)



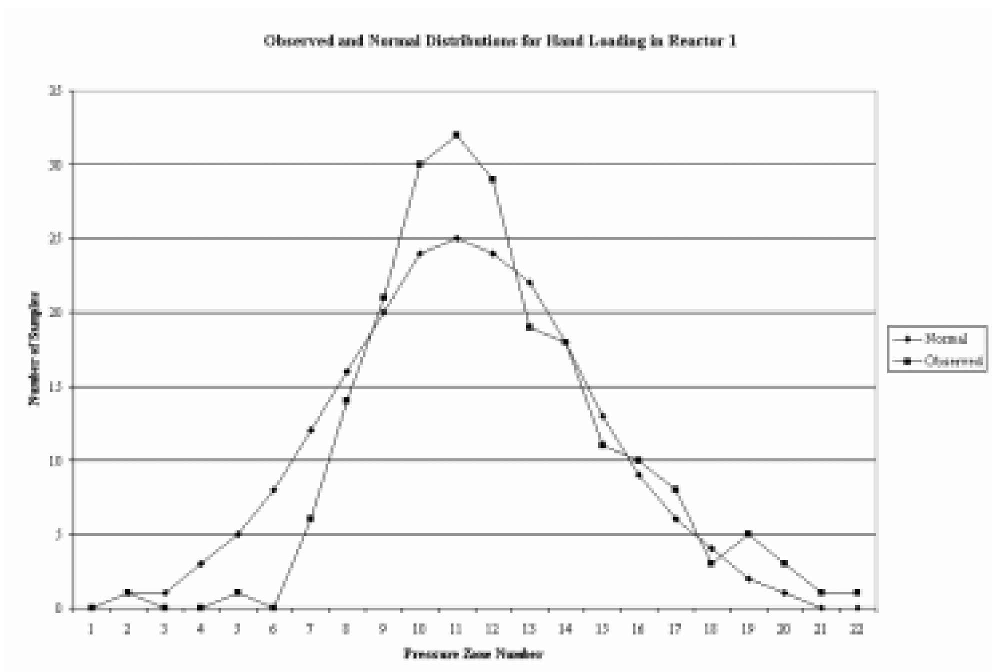


Figure 4. Observed Back-Pressure Distribution Compared to a Normal Distribution Having the Same Mean and Standard Deviation. Shown for Box Loaded Tubes (Top) and Hand Loaded Tubes (Bottom) in the Same Reactor. For use in Chi-Square Analysis