Slipstream Testing of Particulate Filters at the Wabash River Coal Gasification Repowering Project

Final Report

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July 15, 2004

Dear Mr. McMahon:

Under this cover letter please find one copy of the Slipstream Testing of Particulate Filters at the Wabash River Coal Gasification Repowering Project required under Cooperative Agreement DE-FC21-92MC29310.

Should you have any questions on the information contained herein, please contact me at your earliest convenience.

Regards,

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Acronyms and Abbreviations

WRCGRP	Wabash River Coal Gasification Repowering Project
DOE	United States Department of Energy
CCT	Clean Coal Technology
CAAA	Clean Air Act Amendments
E-Gas^{TM}	Formerly Destec's Coal Gasification Technology
WREL	Wabash River Energy Ltd. (formerly Destec)
HGF	Hot Gas Filter
HP	High Pressure
CFCC	Continuous Fiber Ceramic Composites
PSI	Public Service Indiana
SEM/EDAX	Scanning Electron Microscopy/Energy Dispersive X-Ray
SiC	Silicon Carbide
psig	Pounds per Square Inch Gauge
N2	Nitrogen
LLB	Lurgi Lentjes Babcock
LGTI	Louisiana Gasification Technologies Inc.
H_2S	Hydrogen Sulfide
COS	Carbonyl Sulfide

DCS	Digital Control System
PSV	Pressure Safety Valve
O&M	Operating & Maintenance
HHV	Higher Heating Value
OEM	Original Equipment Manufacturer
JV	Joint Venture

1.0 EXECUTIVE SUMMARY

1.1 Background

The Wabash River Coal Gasification Repowering Project (WRCGRP or "Project") is currently the largest single-train gasification facility in the United States, as well as the cleanest coal fired plant of any kind in the world. Its design allows for lower emissions than other high sulfur coal fired power plants and a resultant heat rate improvement of approximately 20% over the previous plant configuration. The Wabash River gasification facility was developed, designed, constructed, started-up and is currently operated by what are now Wabash River Energy Ltd. (WREL) personnel. Wabash River Energy Ltd. is a wholly owned subsidiary of Global Energy Inc. The Project successfully operated through a Demonstration Period from November of 1995 through December of 1999.

The original Project participants, Destec Energy, Inc. (which was later acquired by Dynegy Power Corporation (Dynegy)) of Houston, Texas, and PSI Energy, Inc. (PSI), of Plainfield, Indiana, formed a Joint Venture (JV) to participate in the United States Department of Energy's (DOE) Clean Coal Technology (CCT) program to demonstrate coal gasification repowering of an existing generating unit impacted by the Clean Air Act Amendments (CAAA). The participants jointly developed, separately designed, constructed, own, and are now operating an integrated coal gasification combined-cycle power plant, using Destec's coal gasification technology (now known as E-Gas^{TM} Technology) to repower the oldest of the six units at PSI's Wabash River Generating Station in West Terre Haute, Indiana. In 1999, Global Energy acquired the Project and the gasification technology from Dynegy. The gasification process is integrated with a new General Electric 7FA combustion turbine generator and a heat recovery steam generator in the repowering of a 1950's-vintage Westinghouse steam turbine generator using some pre-existing coal handling facilities, interconnections and other auxiliaries. The Project processes locally mined Indiana high sulfur coal or petroleum coke to produce 262 net megawatts of electricity. In doing so, the Project is also demonstrating some novel technology while advancing the commercialization of integrated coal gasification combined cycle technology.

A full scale Hot/Dry Particulate Removal system is one of several technology improvements being demonstrated at the Wabash River plant. However, the original as-installed OEM filter system had a number of reliability problems that negatively affected plant availability. Early in the startup period it became clear that continued testing and development work would be required to improve the reliability of the hot gas filter system. Initial testing had shown that it was not economically feasible to perform this work in the commercial filters. It jeopardized plant availability and did not always yield meaningful data. For these reasons it was decided to implement a multi-element slipstream unit that could provide reliable data without risking plant production.

In 1996, WREL (formerly Destec) decided to engineer and implement a slipstream unit capable of performing the development work necessary to enhance the reliability and lower O&M costs for the Wabash hot gas filter (HGF) system. In 1997, the U. S. Dept. of Energy provided funding to help support the design, construction and operation of the slipstream system. The unit was successfully commissioned and began operation in November of 1997.

1.2 Slipstream Project Description

In early 1996, the Hot Gas Filter (HGF) Slipstream project was initiated with the generation of its process design package. The detailed design and material procurement phases progressed into the second quarter of 1997. Field construction for the project lasted from April through August of 1997. Several months of commissioning and startup activities followed and the system came on line in November 1997.

The HGF slipstream receives particulate laden gas (640-780 F/350-410 psig) from a tie-point located between the high-pressure steam generator and the commercial HGF. The slipstream filter (V-159) is capable of testing 7 full size candle elements in a single cluster or it can be configured for testing multi-tiered arrangements. Char is periodically removed from the primary filters by pulsing a high pressure (HP) syngas into the "clean" side of the element. The HP syngas (280-400F/750-900 psig) is supplied by the commercial blowback system and is stored in an accumulator vessel (D-158). Fast acting valves are used to simulate blowback conditions in the full-scale unit (~250 - 350 msec). During the blowback cycle, the dislodged char cake falls to the bottom of V-159 and flows into a solids collection and char transfer drum (D-159). Level detectors are used to monitor char accumulation in this vessel. Char is recycled back into the commercial process by using HP syngas in the transfer vessel. Particulate free syngas flows out of V-159 and into a backup filter system that prevents solids from entering the commercial process. The particulate free syngas is recycled back into the process downstream of the commercial HGF.

A Mod5 digital control system, developed by the Dow Chemical Co., provides the automated control and operator interface with the slipstream unit. The control logic for pulse cleaning can be triggered on a manual input, a time increment, or a selected filter differential pressure. A time increment was the typical mode of operation for this controller. This mode of control was typically used to initiate the char transfer sequence as well.

1.3 Slipstream Test Objectives

The Wabash HGF slipstream test program was developed to meet a specific list of objectives focusing on ways to improve operation of the commercial HGF in support of plant production goals. They are summarized as follows:

1. Provide blinding rate and corrosion data to support the development of a filter that exceeds 10,000 hours of operation.

2. Evaluate filter types (various pore sizes, materials, constructions) and supporting hardware configurations that will provide a system capable of operating at 100% reliability.

3. Develop filters, supporting hardware and filter system designs that extend HGF maintenance requirements beyond 6 months.

4. Develop a reliable and low cost backup or fail-safe filter system for the HGF process.

1.4 Results

The Wabash slipstream HGF (Slipstream) began operation in November of 1997 and to date, it has been used to conduct eighteen (18) different test campaigns. The system has accumulated over 4128 hours of syngas operation when feeding Indiana high sulfur coal or petroleum coke to the gasifier. Nineteen (19) different types of filters have been evaluated so far.

Filter blinding trends have been established for twelve (12) variations of metal and ceramic candle filters. Using this data along with plant HGF corrosion studies, a predicted operating life has been determined for five (5) different types of filters. A number of metallic filters developed using the Slipstream are now operating in the commercial process. They are a major reason why the system has performed 100% reliably over the last three and a half years.

Four types of filter hardware configurations were evaluated in the slipstream system. They consist of new types of filter to tubesheet connecting hardware, fail-safe mounting devices and filter bottom restraint systems. The new configurations were evaluated both for reliability in the process and maintenance labor savings. Two types of metallic filter hardware were evaluated in the slipstream unit. One design is now successfully being used in the commercial HGF. The new configuration has proven to be highly reliable and has significantly reduced the maintenance time required to replace a set of candles. Another hardware configuration used for ceramic filters has been proven as a highly reliable system in both the slipstream and commercial processes.

The particulate laden gas entering the commercial HGF was isokinetically sampled using the slipstream system for three (3) different types of gasifier feedstock. One was taken with the plant on Indiana high sulfur coal and the other two consisted of different petroleum coke derived samples. The sample data was used to validate plant process models and for char characterization. Samples have also been used in cold flow evaluations of new equipment.

The slipstream system was used as an initial screening tool when evaluating various metal alloys and ceramic materials for corrosion in the process. Typical evaluations could only provide 250 to 500 hours of data. Due to the difficulty in predicting media corrosion trends, significant runtime is required (in excess of 5000 hrs) to obtain meaningful data. Since it can be structured with essentially no risk to commercial production, these types of studies are better suited for the plant HGF system. This provides optimal media exposure times. Consequently, all long-term corrosion evaluations were conducted in the commercial filter.

A major objective in the slipstream test program was to evaluate a fail-safe device to potentially replace the existing commercial backup filter system. The backup filter was used to contain any solids that might break through the primary HGF. It had proven both unreliable and required significant maintenance expenditures to keep it operational. A major shortcoming of this system was its inability to sustain plant operation when one or more primary filter failures occurred. A fail-safe system offers a number of distinct advantages over the existing backup filter. It has the ability to keep the plant on line even if multiple candles fail and is significantly less costly to install and maintain. There were two major concerns with sustained long-term operation of these fail-safes in the commercial system. Both dealt with fail-safe blinding over time due to either primary filter inefficiencies or from condensation of trace elements in the media. During the study, the increase in overall fail-safe resistance was found to be negligible. The study helped to prove that concerns with fail-safe blinding were unfounded for the Wabash process. Post-test inspections revealed failures in several fail-safe devices. The supplier evaluation found that a manufacturing defect was the root cause for failure. A number of improvements were implemented in both the fail-safe manufacturing process and quality control program to correct this problem. Subsequent testing and operation of the fail-safe device demonstrated that the problems had successfully been eliminated. As a result of these studies, the commercial backup filter was replaced with this type of fail-safe system. The system has proven to be highly effective at preventing solids breakthrough into downstream equipment and is the single most important contributor to the 100% reliability of the commercial HGF over the past three and a half years.

1.5 Conclusions and Technical Insights

The most significant conclusions and technical insights gained from the slipstream studies are listed below.

1. The slipstream unit is a valuable tool for predicting filter behavior in the commercial process. Data from studies involving both metallic sintered powder and sintered fiber elements closely followed the commercial HGF trends while operating with similar types of filters. There was also general agreement in data trends for clay-bonded silicon carbide filters. The similarities in filter behavior between the two systems has shown the slipstream is a valuable tool to evaluate filters being considered for the Wabash HGF process.

2. A fail-safe system is a better alternative to serve as a backup for the primary HGF. It provides much higher HGF reliability and is significantly less costly to operate than a backup filtration system. The fail-safe device selected for the Wabash HGF has proven to effectively prevent solids breakthrough into downstream equipment, and to date, has demonstrated 100% reliability in the process.

3. For metallic candles, those constructed with fiber type media consistently demonstrated the lowest rates of blinding in the Wabash HGF slipstream process. They are much more robust than ceramic candles and are able to withstand a high degree of rough handling during the maintenance process. Metal fiber media has an extremely low corrosion tolerance, but by using newly developed alloys they are capable of providing sufficient life in the process.

4. In general, there were two types of ceramic filters evaluated in this program. They were variations of clay-bonded silicon carbide and oxide composites (CFCC-continuous fiber ceramic composites). Over the course of these studies, the clay-bonded silicon carbide filters had perfect reliability in the process. In contrast, all but one oxide composite filter failed during operation in the slipstream system. The oxide composite filters were found

to have inadequate strength to withstand the rigorous blowback requirements for the Wabash process.

5. For clay-bonded silicon carbide candles, better blinding rates were achieved as the membrane mean pore size was reduced. Optimum blinding rates were generated with the 5 micron mean pore membranes. These blinding rates were comparable to those found in the best metal fiber candles.

6. The HGF slipstream is a useful tool to evaluate new filter hardware configurations for fixing filters to the clean gas plenum and restraining bottom candle movement. In this program, new and unique designs were tested in an actual HGF environment with no risk to plant availability. The hardware was successfully evaluated for both reliability and maintenance requirements

7. In addition to filter evaluations, a slipstream HGF is useful for isokinetically sampling a gas stream containing a high concentration of particulate matter. The slipstream proved invaluable for sampling the solids laden syngas just upstream of the commercial HGF for a number of different types of gasifier feedstock. This data is helpful to validate plant process models for various types of gasifier feed. Characterization of collected char samples will be useful for future plant designs. The char is also used for cold flow studies to evaluate alternate filter and filter/cyclone systems.

2.0 INTRODUCTION

2.1 Overview of the Wabash River Gasification Facility

The Wabash River Coal Gasification Repowering Project (WRCGRP or "Project") is currently the largest single-train gasification facility in the United States, as well as the cleanest coal fired plant of any kind in the world. Its design allows for lower emissions than other high sulfur coal fired power plants and a resultant heat rate improvement of approximately 20% over the previous plant configuration. The Wabash River gasification facility was developed, designed, constructed, commissioned, and is currently operated by what are now Wabash River Energy Ltd. (WREL) personnel. Wabash River Energy Ltd. is a wholly owned subsidiary of Global Energy Inc. The Project successfully operated through a Demonstration Period from November of 1995 through December of 1999.

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The Project has demonstrated the ability to run at full load capability while meeting the environmental requirements for sulfur and NO_x emissions. Cinergy, PSI's parent company, dispatches power from the Project, with a demonstrated heat rate of under 9,000 Btu/kWh (HHV), second only to their hydroelectric facilities on the basis of environmental emissions and efficiency.

In late 1998, PSI Energy reached agreement to purchase the gasification services contract from Dynegy subject to regulatory approval. Regulatory approval was granted in September of 1999 and the sale was completed in October of 1999. This agreement allowed PSI to purchase the remaining term of the 25-year contract, which had become "out-of-market" in comparison to today's alternate sources for power. WREL explored alternatives for continued operation of Wabash River in a more "market-based" mode. In June of 2000, Global Energy Inc. announced that WREL had entered into a competitive market contract with PSI for the sale of syngas. Syngas, sold under this market-based three year agreement, is priced to allow the power it produces to compare favorably year-round to PSI's alternate sources for on-peak and off-peak power.

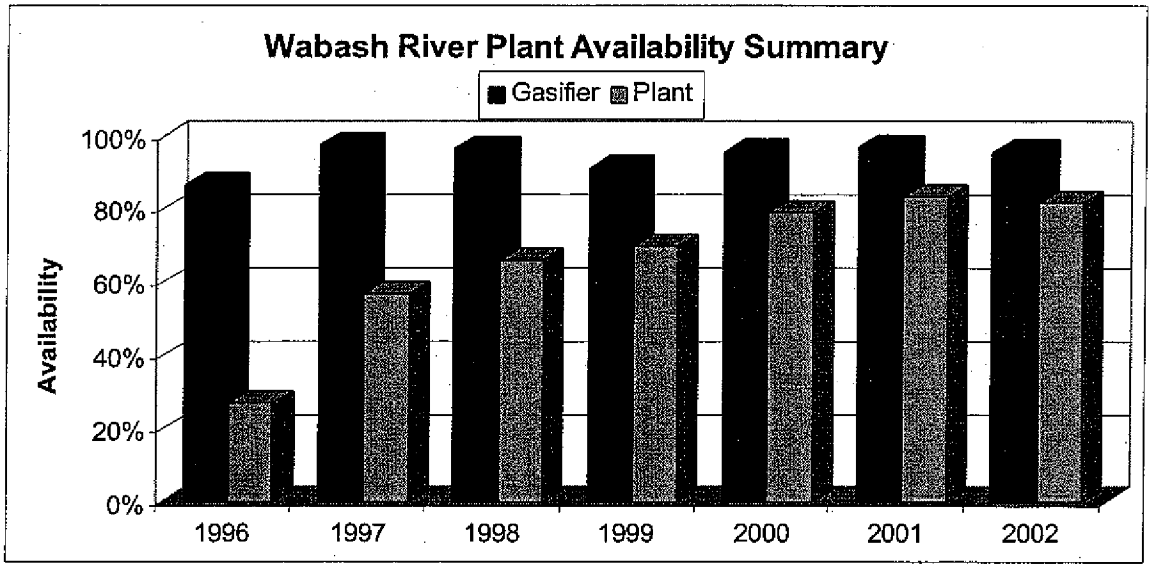
This recent development, coupled with efforts to improve the commercial viability of the Wabash River Coal Gasification Repowering Project, has sharpened the focus to make the technology competitive in today's market. The hot gas filter (HGF) slipstream test program has been instrumental in supporting this effort.

2.2 Wabash River Gasification Facility Operating History

Construction for the WRCGR Project commenced in September 1993 and was completed by July 1995. After a three month period of commissioning, startup, and performance testing activities, commercial operation began in late November 1995.

Table 2.2.1 summarizes annual gasifier and overall plant availability statistics from the beginning of the commercial operating period through the end of 2002. The data shows that 1996 was an extremely challenging year for the facility. Although gasifier availability was at 87%, the plant operated only 27% of the year. Low plant availability was caused by problems in syngas path related processes, gasifier support systems, and in the combined cycle power generation facility. One of the most significant contributors to plant downtime in 1996 was low availability in the hot gas particulate removal system. A number of fast track projects were implemented that improved plant availability in 1997 to 57%. Additional improvements in 1997 and 1998 had increased plant availability close to 70%. By 2000 plant availability had increased to near 80%. The high availability demonstrated since then is a direct result of intensive development work undertaken in both the Slipstream and HGF systems.

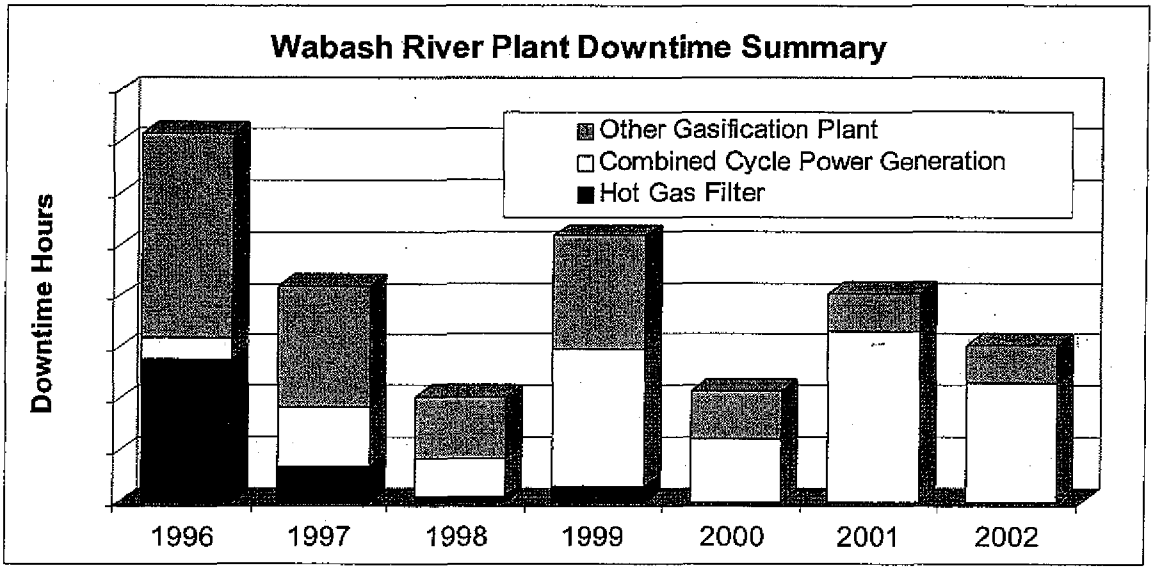
Table 2.2.1: Wabash River Plant Availability Summary



2.3 Hot Gas Filter Startup and Operating History

Table 2.3.1 illustrates the percentage of total downtime hours attributable to the hot gas filter (HGF) system as well plant outage hours caused by other gasification plant processes and the combined cycle power generation facility. In 1996 difficulties in the HGF made up over 39% of the total plant downtime. As HGF improvements were implemented, its operation improved in 1997 with the total attributable downtime being reduced to around 17%. Additional improvements in 1997 and1998 further reduced HGF downtime to below 6% of the total. Using improvements developed in both the slipstream and commercial processes the HGF has demonstrated consistent operation with 100% reliability since 2000.

Table 2.3.1: Wabash River Plant Downtime Summary



During the 1995 - 1996 startup and commercial operating period, a number of reliability problems in the hot gas filter system were quickly identified and corrected. During the initial plant startup char was found breaking through the commercial HGF. The leakage was a result of gasket problems in both the element fixing hardware and filter modular tubesheet flange connections. The problems were easily resolved by changing gasket materials and by implementing a number of changes in the modular tubesheet flange design. As operating time increased, more challenges developed as ceramic candles failed and solids bridging began to occur.

In the original HGF design low reverse flow pressure was measured inside the candle filter during the blowback event. This inadequacy was found to be the root cause for solids bridging that occurred in the candle filters. Several components within the system were re-sized to correct this problem.

Another source of candle bridging and breakage resulted from mixing filters of various flow resistances (or permeability) within the primary vessels. Post-operating inspection data showed that installing a new cluster of filters in a vessel full of conditioned (or used) candles typically led to bridging and resultant ceramic candle breakage within that cluster. Breakage also occurred in the new filters due to the extremely high instantaneous face velocity that resulted immediately after the backpulse event. Filter conditioning periods (at low production rates) during plant startup and changes in vessel candle loading practices were used to mitigate this problem.

The initial candle elements used in the Wabash hot gas filter was a ceramic clay-bonded SiC type. Failures of candle filters in 1996 caused at least 5 major plant outages. Candle breakage resulted from a number of sources such as bridging, improper handling, and filter fixing hardware problems. As a result, the system was retrofitted with metal candles late in 1996.

Another problem in the HGF was caused by flow imbalances in the vessel internal gas/solids distribution system. The distribution system was designed to direct the incoming dirty gas evenly over the upper section of the candle filters. High filter impingement velocities from gas exiting the internal gas distributor caused erosion on the candle surface and resulted in blinding (loss of permeability) the filters at these locations. Filter permeability was totally lost in the areas of high velocity gas impingement. High erosion rates on some distributor parts also yielded low component life and required frequent vessel internal repairs. Several improvements were implemented to this system to significantly improve its performance and reduce filter impingement velocities.

During the 1995-1996 operating period, many improvements were implemented to address the above-mentioned challenges and they significantly increased the reliability of the Wabash HGF system. However, additional improvements would be required to enable the system to meet specific performance goals. This required further development work in a number of areas. Accelerated filter blinding continued to be a concern since it limited filter life and necessitated frequent filter replacement or cleaning (off-line). Consequently, this was a key focus in the filter development program. Filter corrosion was also a concern when operating metal candles with high sulfur coal and petroleum coke feedstock. Additional improvements were required for the internal gas distribution system to further increase component life as well as minimizing filter surface gas impingement velocities. It soon became obvious that many of these improvements could best be developed utilizing a slipstream system.

2.4 Slipstream Program Objectives

To position the E-Gas process as a competitive and marketable technology the Wabash plant had to achieve specific operating and maintenance goals. Given the hot gas filter is an essential part of the gasification process, it must be a highly reliable system. Early on, specific performance goals were established for the Wabash HGF. The goals were no attributable lost plant availability, a 10,000 hour minimum filter life and a 7500 hour HGF maintenance frequency.

The original hot gas filter selected for the Wabash facility was designed by the OEM to provide 100% reliability between scheduled maintenance outages. However this was not the case. During the plant startup period, it became evident that significant testing and development work would be required to achieve this reliability. It was also evident that much of the development work could not be performed in the commercial process since it would jeopardize plant availability and could not always be structured to provide meaningful data. Full scale testing would require significant maintenance expenditures as well. Consequently, a decision was made to implement a multi-element slipstream unit that could provide reliable data without risking plant availability.

Utilization of a slipstream test unit is better suited to test unproven filter types and system modifications without risking availability of the commercial process. It also provides more accurate blinding studies since the filters being tested have similar permeability. Previous blinding studies conducted in the full size vessels required installing new test elements in with different and/or conditioned (previously used) filters. Consequently, the data often yielded somewhat questionable results. The slipstream unit also provides crucial data for new HGF systems to be used at future gasification facilities. Data such as particulate loading, char characterization, and backpulse requirements for various types of feedstocks are essential to design alternate types of filter systems. By utilizing the slipstream system, process conditions can be altered to determine how they affect filter performance. Conducting these studies on a smaller scale is a much more cost effective approach.

2.5 Slipstream Test Program

2.5.1 Test Objectives

The primary objective in this program was to evaluate various types of candle filters in the E-gas gasification process to identify those that provide optimum performance and reliability. The objectives set forth in this test program were established to improve the reliability of the Wabash River coal gasification facility and reduce its operating costs. Supporting objectives are as follows:

1. Establish a list of acceptable materials for filter element fabrication by demonstrating the effectiveness of porous metal and ceramic filter elements in the E-gas process.

2. Determine the optimum filter element (pore size, material, construction) for use in the E-gas gasification process.

3. Gain insight on the mechanisms that cause accelerated hot gas filter blinding and determine what parameters can be changed in the commercial vessels to improve filter system availability.

4. Determine the optimum backpulse system operating parameters to efficiently clean hot gas filter elements.

5. Gain insight on the mechanisms that cause char bridging within filter clusters and implement noted operating parameter improvements in the commercial vessels.

6. Gain insight on the mechanisms that cause ceramic element breakage and identify corrective design modifications.

7. Measure the syngas stream solids loading into and out of the hot gas filter system so material balances can be performed. Also perform characterization studies on char derived from coal

and petroleum coke feedstocks.

8. Evaluate alternate filtration systems that will adequately backup the Wabash primary filters and reduce current O&M costs. This system should protect downstream equipment from damage caused by solids breaking through the primary filter. It should also allow the plant to remain on-line if breakthrough occurs in the primary filter system.

9. Establish design criteria for constructing future hot gas particulate filter systems.

2.5.2 Basis for Test Selection and Prioritization

- The Wabash River coal gasification facility was designed to run high sulfur coal feedstock. The facility also operates on petroleum coke, which has a much higher sulfur content (increase from 2% to 5%). This increase could accelerate corrosion rates in porous metal filters while operating in the process.

- Recent studies indicate that vapor phase condensation of trace metals on candle filters and in the residual (non-transient) char layer is causing an accelerated rate of blinding. Plant data has shown these blinding rates will change for different types of filters. In addition to alternate filter types, studies may be performed to determine if certain process changes can improve blinding rates.

- Membrane type ceramic candles of various pore size have been tested in the Wabash commercial hot gas filter system. Pre- and post- test filter resistance data indicates that a reduction in membrane pore size may lower filter blinding rates.

- Utilization of major equipment currently in operation at the Wabash gasification facility must be considered in achieving the Test Program objectives.

- The original backup or secondary char filtration system in the Wabash gasification process has experienced significant numbers of failures since plant startup. The failures result in low secondary filter system availability as well as high O&M expenditures. This places a high priority on improving or replacing this system.

- Operating experience in the Wabash HGF has provided some insight into the formation of candle element bridging. Post-operating inspections have shown that mixing filters of various resistance (for example: new and old) results in bridging of the lower resistance candles. Also, flow imbalances between the two HGF vessels can contribute to element bridging. Since utilizing these learning experiences, element bridging has not been a significant problem in the commercial vessels and for this reason it will be a low priority objective for the test matrix.

- Minimum blowback pressure and reverse pulse time have been studied to some degree in the commercial hot gas filter unit. This study has provided a set of guidelines that has proven useful in operating the HGF system. For this reason, backpulse optimization studies will be considered a low priority objective for the test matrix.

- Studies to evaluate alloy corrosion rates have been ongoing since metal filter testing was initiated in the commercial vessels (early 1996). Due to the long test periods required to obtain meaningful data, these studies will continue to be performed in the commercial vessels.

2.5.3 Test Evaluation Methods

The following methods were used to evaluate filters tested in the Wabash slipstream system. For more detail refer to Section 4.1.

1. Plant data acquisition systems were used to collect operating data for the slipstream unit. The data was used to calculate blinding rates for comparison with various filters and/or process changes. Blinding rates were also compared to plant data for various types of filters previously operated in the Wabash HGF.

2. Scanning electron microscopy/energy dispersive x-ray (SEM/EDAX) was used to perform micro structural analysis of filter residual dust cake layers and to study particle/vapor phase deposition within the filter substrate.

3. Characterization of residual dust cake layers and substrate deposition using EDS mapping.

4. Material strength/ductility evaluations using C-ring/O-ring compressive and/or tensile testing methods. Also hoop stress tests were used to determine strength changes in sintered metal type filters.

5. Pre and post-test evaluation of filter permeability was made using a single element air flow test unit.

6. Metallurgical examination using both light and scanning electron microscopy (SEM).

2.5.4 Standard Operating Parameters

Listed in Table 2.5.4.1 are the standard operating parameters for the Wabash HGF slipstream system.

Table 2.5.4.1 Slipstream Operating Parameters

Filter Vessel Temperature	640 - 780 F
Filter Vessel Pressure	350 - 410 psig
Filter Inlet Mass Flow	2476 lb/hr
Filter Face Velocity	2.5 fpm
Char Solids Loading	46.8 – 49.4 lb/hr
Blowback Gas Pressure	775 - 880 psig
Blowback Gas Temperature	280 - 390 F
Blowback Duration	250 - 350 msec.
Blowback Cycle Time	84 sec. (total)
Char Bulk Density	13.7 lb/ft^3 (coal)
Char Permeability	0.45 nPm (coal)
Char Mean Particle Size	20 - 25 μ (coal)

2.5.5 Test Matrix

The original test matrix proposed for the slipstream study is located in Table I-1in Appendix 1. A summary of the actual testing performed is provided in Table 2.4.5.1 below. A significant portion of the test program was developed to meet specific plant HGF development needs. The original test matrix was developed in late 1996. It was based on projected plant and technology development needs that were evident at that time. As HGF system reliability increased development priorities changed. Consequently, a number of tests proposed in the original matrix were not performed. Other tests were substituted to improve reliability and reduce the maintenance required for the commercial facility.

Table 2.5.5.1 Slipstream Test Program

Test No.	Test Description	Filter Type	Duration (hours)	Operating Parameters	Objectives (Section 2.5.1)
1	Isokinetic Sampling of a Petroleum Coke Derived Syngas	Metal Fiber	30	See Table 2.5.4.1	7,9
2	Isokinetic Sampling of a Coal Derived Syngas	Metal Fiber	15	See Table 2.4.4.1	7,9
3	Filter and Fail-Safe Evaluation	Metal Fiber	263	See Table 2.4.4.1	1,2,8
4	Filter Evaluation	Metal Powder	564	See Table 2.4.4.1	1,2,3
5	Filter Evaluation	Ceramic SiC	239	See Table 2.4.4.1	1,2,3
6	Filter and Fixing Hardware Evaluation	Ceramic SiC	375	See Table 2.4.4.1	1,2,3,6,9
7	Filter Evaluation	Iron Aluminide Powder	423	See Table 2.4.4.1	1,2,3
8	Filter Evaluation	Metal Fiber	158	See Table 2.4.4.1	1,2,3,9
9	Filter Evaluation	Ceramic SiC	235	See Table 2.4.4.1	1,2,3
10	Filter Evaluation	Metal Fiber	257	See Table 2.4.4.1	1,2,3,9
11	Filter Evaluation	Oxide Composite	29	See Table 2.4.4.1	1,2,6
12	Filter Evaluation	Oxide Composite	290	See Table 2.4.4.1	1,2,6
13	Filter Evaluation	Metal Fiber	300	See Table 2.4.4.1	1,2,3,9
14	Filter Evaluation	Metal Powder	114	See Table 2.4.4.1	1, 2,3
15	Isokinetic Sampling of a Petroleum Coke Derived Syngas	Metal Fiber	12	See Table 2.4.4.1	7,9
16	Filter Evaluation	Metal Fiber	620	See Table 2.4.4.1	1, 2,3,9
17	Filter Evaluation	Oxide Composite	188	See Table 2.4.4.1	1, 2,6
18	Isokinetic Sampling of a Petroleum Coke Derived Syngas	Metal Fiber	12	See Table 2.4.4.1	7,9

3.0 PROJECT DESCRIPTION

3.1 Project Overview

In 1996, WREL decided to implement a slipstream unit to support the development work necessary for improving the reliability of the Wabash HGF system. In 1997, the U. S. Dept. of Energy provided funding to help support the design, construction and operation of a multi-element HGF slipstream unit at the Wabash facility.

When designing the Slipstream system, specific criteria was established to ensure it would provide relevant data. Another important aspect was to ensure the flexibility to test alternate filter types and various system configurations. To develop this, a comprehensive list was generated detailing various improvements that could be studied in the slipstream unit. The list includes specific studies required to increase Wabash HGF reliability and those used to support development work for future gasification facilities. The design criteria used for the Slipstream system is as follows:

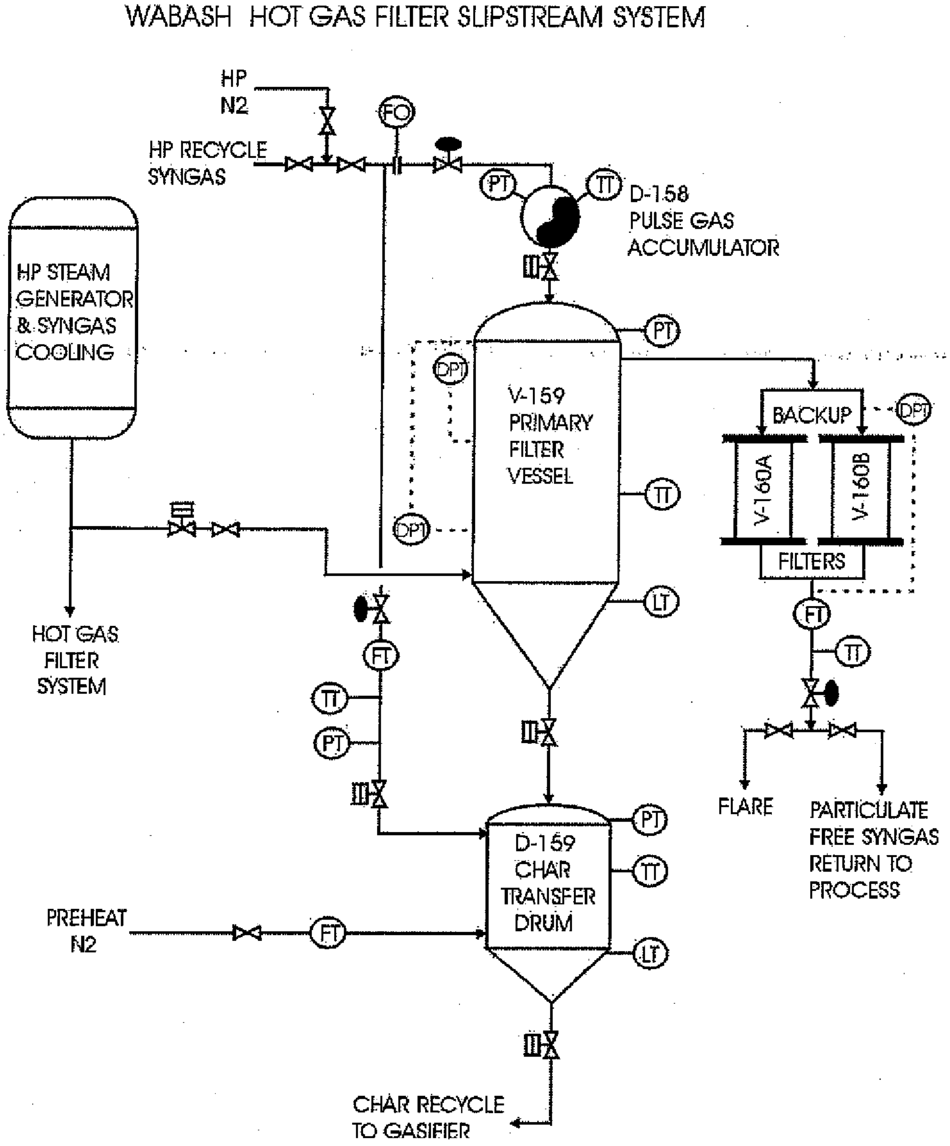
- Design into the system the capability to test various filter types (candles, honeycomb, etc.), lengths, hardware configurations, and system arrangements such as multi-tiered designs.
- The slipstream system should be designed to test multiple filters in a similar cluster type arrangement as is used in the commercial scale vessels.
- The slipstream system should fully simulate process conditions in the commercial scale vessels such as gas composition, gas pressure, gas temperature, solids loading, filter face velocities, backpulse conditions, and char recycle capabilities.
- The system must be capable of performing re-entrainment studies so that alternate configurations for internal gas distribution can be studied.
- The slipstream system must be capable of testing various types of secondary or backup filtration systems.
- Flexibility must be built into the system so that blowback optimization studies can be performed.

The WREL (formerly Destec) engineering group generated a process design package for the slipstream project in early 1996. The Dow Chemical Engineering and Construction group in Houston, Texas performed the detailed design engineering. This effort was kicked off in late-May of 1996 and was completed by the middle of the 3rd quarter of that same year. Material procurement was initiated for the project during the late phases of detailed design and was completed by mid-second quarter of 1997. Procurement was slightly delayed due to the project getting placed on hold for the winter months and as a result of shifting manpower requirements to complete other higher priority plant projects. Field construction kicked off in late April of 1997 and was completed by August of that same year. Several months of commissioning and startup activities followed and the system came on line in November 1997.

3.2 Process Overview

This section provides an overview of the Wabash Slipstream process. Figure 3.2.1 illustrates the process described in this section.

Figure 3.2.1 Slipstream Process Flow Diagram

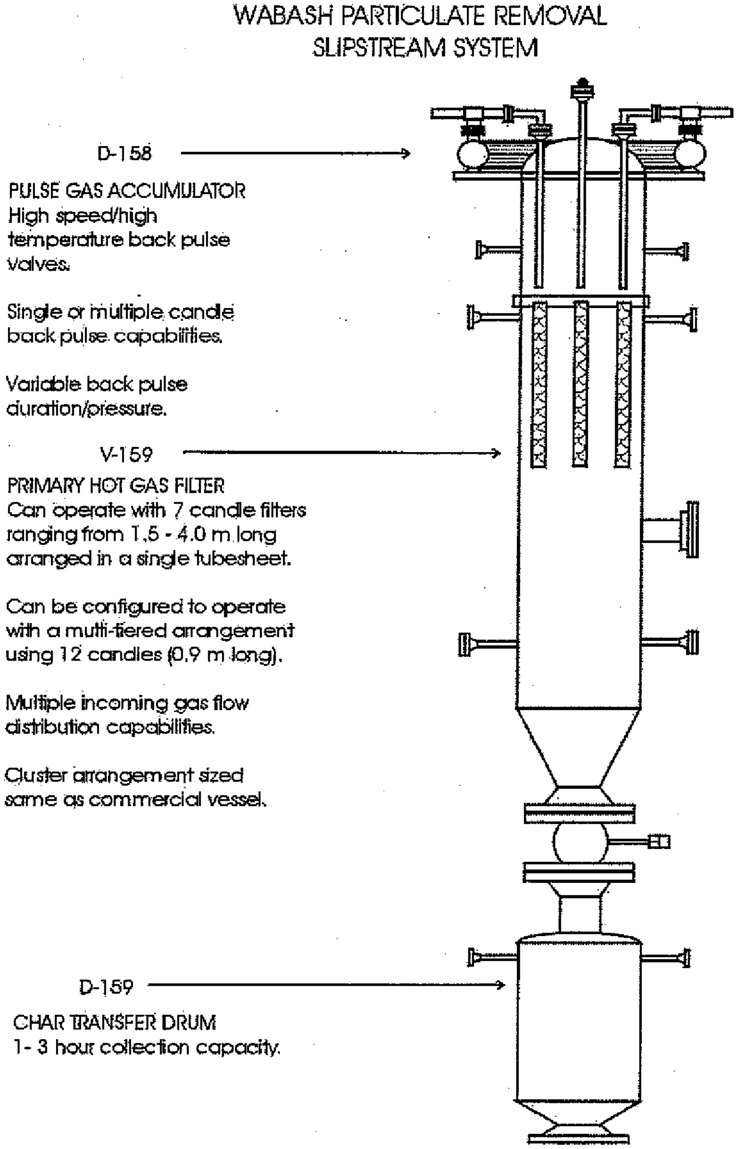


The slipstream HGF, located at the Wabash River Gasification facility, is configured to operate utilizing the same process syngas as is fed to the commercial particulate removal system. As in the commercial process, the incoming "dirty" gas enters the primary filter vessel, V-159, at 650 – 800 F and 360 – 420 psig. Particulates entrained in the gas stream consist of ash carryover from the gasifier first stage process and partially reacted coal particles from its second stage process. The particulate matter, high in carbon, is classified as char. The "dirty" syngas is removed from the process just upstream of the commercial HGF through an isokinetically designed nozzle. The slipstream of gas then enters V-159 through an internal gas distribution system that directs the flow downward over the outer surface of the candles. Particulates are removed from the gas as it flows through the filters into the clean gas plenum. The particulate free syngas leaves V-159 where it flows through a secondary or backup filtration system (V-160 A/B) and is recycled back into the commercial process. The solids that collect on the primary filters are periodically removed by using a high-pressure recycled syngas to momentarily reverse gas flow through the element. High-speed automated valves configured over a nozzle and venturi arrangement are used to regulate the blowback flow. The high-pressure recycled syngas is the same as that used to blowback the commercial hot gas filters. This gas is stored in D-158, the blowback gas accumulator. The char cake is dislodged from the filter and falls to the lower section of V-159. It then flows downward into D-159, the char collection and transfer drum. The char is collected in D-159 for a specified period of time after which it is transferred back into the commercial process using high-pressure recycled syngas. Process ties into the plant nitrogen and flare systems enable the Slipstream unit to be purged and preheated up to process temperatures.

3.3 Filter Vessel

Figure 3.3.1 shows the general vessel layout for the slipstream system. Sections 3.3 – 3.5 provide a detailed description of the vessels used in the Slipstream system.

Figure 3.3.1 Slipstream Vessel Configuration



The primary filter, V-159, consists of an 18 inch diameter 15 foot long pressure vessel designed to operate at commercial filter conditions (see Table 2.5.4.1). The standard configuration uses a single tubesheet to separate the clean gas plenum from the incoming dirty process gas (see Figure 3.3.1). The tubesheet is designed to contain up to seven candle filters ranging from 1.5 – 4.0 meters long. The filters are arranged to maintain the same spacing as is used in the commercial vessels. During the test program, a number of methods were evaluated for holding the filter in the tubesheet. An internal gas distribution system is used to prevent direct impingement of the incoming gas on the candle filters. The incoming gas exits the distribution system near the top of the candles and flows in a downward direction across the candles. Nuclear level devices are used to detect any char bridging that may occur at the bottom of the vessel. Flexibility is incorporated into the vessel design so it can also be configured to operate with a multi-tiered arrangement such as the Lurgi Lentjes Babcock (LLB) Energietechnik GmbH design. A high temperature heat trace and insulation system is used to maintain the vessel at process operating temperatures. This system is also useful for preheating the vessel above the syngas moisture dewpoint prior to placing the unit on-line.

3.4 Blowback System

The blowback system utilizes high pressure (HP) syngas to periodically remove the solids that are collected on the primary filter elements. It consists of a pulse gas accumulator, D-158, seven (7) high speed/high temperature automated valves, and a nozzle and venturi system to regulate gas flow into the filters. The gas accumulator is made up of a "U" shaped arrangement of 12 inch diameter stainless steel piping. It's designed to operate at commercial blowback system conditions (see Table 2.4.4.1). A high temperature heat trace and insulation system is used to maintain the accumulator at process operating temperature. Seven (7) high-speed valves are used to provide a short burst of gas into the clean side of each filter. The valves are capable of going fully open to fully closed in just over 100 msec. The blowback duration is adjusted by the time increment of the electrical input into the valve solenoid. Flexibility is incorporated within the control system to blowback each filter individually or together as a cluster. The control logic for blowback cleaning can be triggered on a manual input, a time increment, or a selected filter differential pressure. The time increment mode was typically used for this controller. Various pulse tube and venturi arrangements are used to facilitate fail-safe testing.

3.5 Char Transfer System

The char transfer system is used to recycle solids collected in the slipstream unit back into the commercial process. The recycle system selected for the slipstream has proven to be highly reliable for this process. The char collection drum, D-159, is an 18 inch diameter, ~ 6.5 foot long pressure vessel designed to operate at process conditions. High pressure syngas is supplied to the drum to periodically recycle char back to the process. A high temperature heat trace and insulation system is used to maintain the transfer drum at process operating temperatures. Nuclear level devices are included on the vessel to monitor char accumulation in the drum. The char transfer sequence can be triggered using the solids level indication or on a timed increment. A timed increment was the typical mode used to trigger the char transfer process.

3.6 Backup Filter

Backup filters were included in the slipstream system to prevent solids from entering the commercial process in the clean syngas recycle stream. The backup filters, V-160A/B, utilize a large porous honeycomb type membrane coated ceramic filter. Each filter is contained within a high pressure housing. Both filters are not configured for on-line regeneration.

3.7 Controls and Data Acquisition

A Mod5 digital control system, developed by the Dow Chemical Co., provides automated control and operator interface with the slipstream unit. Its primary features include redundant computers and I/O cards to enhance reliability and reduce control system induced interruptions in operation. The programming language used for this control system is similar to Fortran. Program control code was generated for the slipstream using in-house expertise. The control schemes are readily accessible by the operations staff and many of them have the capability to modify the code as needed. Data acquisition is also accomplished using the Mod5 system. Third party software programs are used to graphically display slipstream data for analysis.

4.0 RESULTS

4.1 Test Methodology

The methods described below were used for slipstream evaluations to help predict filter performance in the commercial process.

4.1.1 Filter Blinding Life Predictions

Blinding rate is best defined as an increase in the resistance to flow through a filter as a function of operating time. Increasing resistance is caused by a number of variables. Small particles migrate into the filter substrate causing an obstruction in the available flow area. In addition to this, small particles have an affinity to form bonds (electrostatic or other) with other particles and to the filter media. This formation creates a conditioned or residual char layer that remains on candle surface even during the blowback event. Given that smaller particles form stronger attracting bonds they tend to make up a significant portion of the residual layer. This reduces surface porosity and further impedes gas flow through the filter. In the Wabash process, a number of trace elements in the process gas stream contact the candle filters while still in a molten or vapor form. Many of these elements (As, Ge, Sb, etc) are collected in the non-transient layer and negatively affect its permeability. The end result is seen as a slow steady rise in HGF resistance over time. Eventually, the resistance is sufficient to render the blowback system incapable of delivering a reverse flow through the candles. When this occurs the candles can no longer be regenerated with the system on line. This limit is well understood for the Wabash HGF vessels and is used to predict filter life. Using this limit and a reliable data trend that depicts resistance as a function of time, a filter blinding life can be projected for the Wabash process.

The first 50 - 100 hours of operation for a new filter is typically a period during which a residual char layer forms on the outer surface of the candle. It's called a residual layer because it remains attached to the candle during the blowback event. This is commonly referred to as the "conditioning period" and is typically characterized by a rapid increase in filter baseline differential pressure. Once the filter is conditioned, the rise in baseline differential pressure becomes much more linear with a noticeable decrease in the upward slope of the data. As a result, the conditioning period is typically neglected when determining filter life. This allows a linear fit of the data to be used for calculating blinding life. The method has proven highly effective at predicting filter life in both the slipstream and commercial processes.

4.1.2 Filter Efficiency

Filter efficiency is best measured by extracting an isokinetic sample out of the "clean" gas stream near the outlet of the primary filter vessel. The solids collected in this sample can be used to calculate the particulate loading in the gas stream. This measurement is normally collected using some sort of isokinetic sample system. Unfortunately, the Wabash facility does not have a device such as this. Consequently, a true filtration efficiency could not be quantified for any of the candles involved in this test program. However, since a secondary filter is used to backup the primary filter, a qualitative evaluation was possible. These were made using blinding data in the backup filters. This would typically indicate a gross problem with filter leakage. For the purposes of these studies, it provides sufficient data to validate acceptable filter efficiencies for the Wabash process.

4.1.3 Isokinetic Gas Sampling

Since the syngas fed to the Slipstream is removed from the process through an isokinetically designed nozzle, it can be used to sample the particulate laden gas just upstream of the commercial HGF. Sample time periods varied depending on the quantity of char needed for analysis. The sample quantity is also used to calculate the solids loading in the syngas entering the commercial HGF. This data is useful for validation of plant process models.

4.1.4 Filter Reliability

Both filters and filter hardware configurations were evaluated for reliability in the process using the Slipstream system. Typical evaluation periods were planned for 250 – 500 hours of operation. Backup filter (V-160) blinding rates and detailed post-test inspections are used to evaluate reliability.

4.1.5 Corrosion Studies

For the most part, corrosion evaluations are conducted in the commercial HGF. The reason for this is that it provides the maximum amount of process exposure time. However, on several occasions the Slipstream was used to provide an initial evaluation of newly developed alloys. It typically was used when a new media alloy became available and the commercial unit was in service and scheduled to remain on line for an extended period of time. Given the limited run times for each campaign, the corrosion data was not sufficient to predict filter life. This data was used to determine if further evaluation in the commercial process was warranted.

4.2 Operating Summary

The Wabash HGF slipstream (Slipstream) began operation in November of 1997 and to date, it has been used to conduct eighteen (18) different test campaigns. The system has accumulated over 4128 hours of syngas operation when feeding Indiana high sulfur coal or petroleum coke to the gasifier. Nineteen (19) different types of filters have been evaluated so far.

The matrix of tests conducted in the Slipstream was structured to address the most pressing filter development needs for the facility. Most test campaigns were scheduled to last from 250 – 500 hours in duration. On several occasions, the system was used to obtain an isokinetic char sample with the plant operating on various types of gasifier feedstock (coal and petroleum coke). An outline describing each operating campaign is provided in Table 2.4.5.1. The results from each test campaign are described in the following sub-sections.

4.2.1 Cold Flow Testing

In 1995, a cold flow particulate removal system was constructed at the Dow Chemical Inc. Michigan Division to help support development work for the Wabash facility. The cold flow unit provided critical design and operating data for the Wabash hot gas filter system. The system operated on ambient air and coal char collected from Destec's Louisiana Gasification Technologies Inc. (LGTI) facility. The filter vessel used a tubesheet to contain up to seven candle elements that were fixed in a cluster arrangement. The tubesheet separated the dirty incoming gas from the clean gas plenum. A pneumatic conveying process was used to recycle the char in a closed loop system.

Early studies in the cold flow unit focused on various aspects of filter bridging and solids reintrainment so that a set of startup guidelines and key operating parameters could be developed for the Wabash HGF.

By early 1996, cold flow studies centered on many of the problems causing low reliability in the HGF process. At this time, ceramic candle failures were one of the most significant contributors to lost availability at the Wabash plant. For this reason, an aggressive effort was launched to develop a reliable metal filter as a potential solution to this problem. As in most evaluations, two of the major points of concern were candle blinding and corrosion. Corrosion studies were initiated for media alloy candidates in the commercial HGF process. The cold flow unit was used as an initial screening process to establish blinding trends for alternate types of both metal and ceramic candle filters. The mode of blinding in the cold flow unit was basically caused by particle penetration into filter pores and to some extent, by the development of a residual layer of char on the candle surface. However, this did not include the effects of other constituents within the process syngas and therefore could not provide definitive rates of candle blinding. Although it could not accurately predict filter life, the cold flow filter did provide an overall trend for candle blinding behavior. The data generated in these studies was especially useful for comparing various types of filters and selecting those that would provide the best performance in the commercial process. The cold flow studies were extremely useful in developing the test matrix for the Wabash HGF slipstream.

4.2.2 Test Campaign 1 (11/25 to 11/26/97)

The first Slipstream test was structured with two purposes in mind. First it provided a shakedown of the newly installed system. There were a number of operational issues and instrument problems identified during this operating period. However, the main purpose of this study was to isokinetically sample the solids laden gas upstream of the commercial filter system. The char sample was collected while a petroleum coke gasifier feedstock was being tested at the facility. After transferring the gasifier feed to 100% petroleum coke, the slipstream unit was placed on line. After achieving stable operation, several char samples were collected. The data obtained was used to validate solids loading to the commercial filters in the facility's process model (Heat & Material Balance). Characterization of the char was also performed with the sample collected in the study.

4.2.3 Test Campaign 2 (2/10/98)

The second operating period for the Slipstream was similar to the first campaign. In this test the gas stream was again isokinetically sampled to determine solids loading to the commercial filters. This study differed in that the gasifier feed was now Indiana bituminous coal. As in the first test, the data was used to validate process models. The sample also provided characterization data for coal-derived char.

4.2.4 Test Campaign 3 (3/12 to 3/23/98)

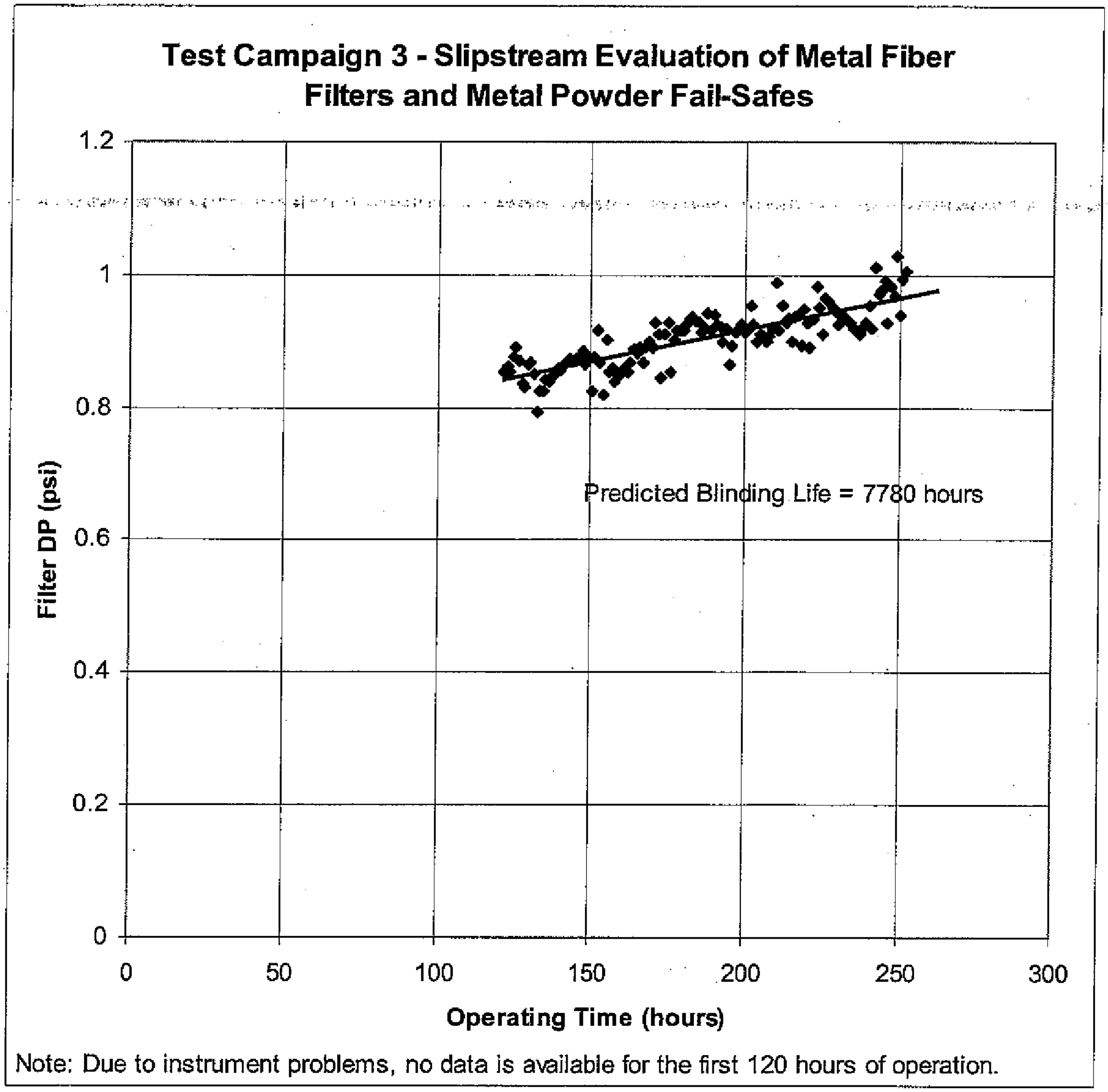
Test Campaign 3 was the first evaluation of a new candle filter in the Slipstream unit. The study was structured to help meet the objectives stated for Test No. 2 in the original test matrix plan (see Table I-1 in Appendix I).

In this test, seven (7) 1.5-meter long metal fiber media candles were evaluated in the slipstream unit. The study's primary focus was to establish a blinding rate to be used for predicting filter life in the commercial process. The media alloy was being developed as a viable candidate to provide optimum filter life when considering both corrosion and blinding as primary life limiting factors. At the same time, this type of candle was undergoing corrosion evaluation in the commercial process and so far it had produced favorable results. However, a reliable blinding trend could not be obtained due to the mixture of filter types being operated in the commercial HGF. An equally important part of this study was the evaluation of a fail-safe device constructed of sintered powder media. Of particular interest was whether the fail-safe would blind from solids passing through the primary filters. At that time, it was unclear if these candles would filter coal char with a high degree of efficiency. Another issue concerned fail-safe media blinding caused by trace elements condensing as the process gas passed through the device. This was especially concerning given the cooler temperatures of the blowback gas. Additional data was required to determine if there would be enough energy in the blowback gas to adequately clean the candle after taking a pressure drop across the fail-safe device. Finally, the last objective to be studied was the overall contribution to filter system resistance caused by the fail-safe devices.

The test was scheduled for 250 hours of syngas operation. The actual run time for the campaign period was 263 hours. A number of instrument and equipment problems were identified and corrected during the operating period. This was not surprising given that it was the first sustained run for the Slipstream unit. Some key operating data was lost at the onset of the campaign due to the instrument problems. However, enough data was generated to adequately satisfy the objectives set forth for the study.

A primary objective in this study was to generate a blinding trend for the candle filters. Using this trend, a filter blinding life was predicted for the commercial process. Figure 4.2.4.1 shows the increase in filter differential pressure as a function of time for the operating period. Using the methodology described in Section 4.4.1, the data collected in this study predicts a filter blinding life of 7780 hours. Both this result and those generated in the HGF corrosion studies helped qualify this filter as a viable candidate for the commercial process. This predicted life was significantly higher than the life of the candles that were currently operating in the commercial process. As a result, a full set of these filters was installed in the Wabash HGF in early 1998. After operating for over 1800 hours in the commercial HGF, the blinding trend was comparable to that predicted by the Slipstream unit. This helped to establish confidence that the slipstream unit is a reliable tool for predicting blinding behavior in the commercial process.

The second objective in the study was to evaluate a fail-safe device as a potential replacement for the Wabash backup filter system. The original backup system utilized in-line honeycomb type filters that could be regenerated on line. The backup filter had proven unreliable and required significant maintenance expenditures to keep it operational. A major drawback to this system was with its inability to keep the plant on-line when one or more primary filter failures occurred. Numerous failures had occurred in the backup filters due to its rigorous blowback cleaning requirements. Since they could not sustain plant operation with primary filter leakage, they were only useful to detect char breakthrough, and to prevent it from contaminating downstream equipment. The fail-safe system evaluated in this study offers several distinct advantages over the existing backup filter. It has the ability to keep the plant on line even if multiple candles fail and is significantly less costly to install and maintain. Prior to this study, there were two major concerns with sustained long-term operation of these fail-safes in the commercial system. The first concern was that the fail-safe would blind over time due to inefficiencies in the primary filter. Given that the primary filters were not 100% efficient, one question to be answered was whether the small amount of char that did get through the primary filter would end up blinding the fail-safe media to the point that the filter could no longer be effectively backpulsed. The second concern was a potential increase in fail-safe resistance due to a buildup of trace elements in the media. Specifically, the concern was that vapor phase trace elements in the syngas might condense in the fail-safe media after being cooled by the backpulse gas. Previous studies had



Note: Due to instrument problems, no data is available for the first 120 hours of operation.

Figure 4.2.4.1: Test Campaign 3 - Slipstream Evaluation of Metal Fiber Filters and Metal Powder Fail-Safes

shown that condensation of certain trace elements such as arsenic, germanium, lead and antimony were found both in the filter substrate and in the residual char layer on the candle surface. Given that many of the same trace elements were found in downstream equipment it was assumed that a certain percentage of them were passing through the filters. This raised the concern that trace metals might also condense in the fail-safe media each time it was cooled by the backpulse gas. To evaluate this, air flow vs. pressure drop measurements were made for each fail-safe device before and after the campaign. From this data a pre- and post-test resistance was calculated for each fail-safe. The results showed that only a slight increase in resistance had developed across the fail-safes during the campaign. The increase was negligible when compared to the overall resistance through the filters. The study helped prove that both suspected modes of fail-safe blinding would not occur to any significant degree in the Wabash process.

Post-test inspections revealed two failures in the seven fail-safe devices. The failed devices were returned to the vendor for root cause evaluation. Both failures were found to be caused by a manufacturing defect. To address this, a number of improvements were implemented in both the fail-safe manufacturing process and quality control program. Subsequent testing and long-term operation of the fail-safe device has demonstrated that these problems were successfully eliminated.

Another key part of this study was to determine if the fail-safes would negatively affect blowback cleaning of the primary filters. Calculations predicted that the pressure drop across the fail-safe was negligible and that it would not affect the blowback cleaning. Unfortunately the filter cavity pressure could not be measured during operation due to a problem in the data collection for this system. However, post-test observations showed no evidence of solids bridging between the filters and a "normal" residual char layer on the candles. The on-line pressure drop across the candles was extremely low and well within the expected range. The results showed the fail-safe pressure drop to be negligible and provided sufficient evidence that the blowback gas effectively cleaned the primary filters.

As a result of this study, the commercial backup filter system was replaced with this type of fail-safe device. This change was a major contributor to the increasing plant availability in 1998. The fail-safe system plays a key role in maintaining 100% HGF reliability at the Wabash plant.

4.2.5 Test Campaign 4 (3/31 to 4/28/98)

The fourth Slipstream test was structured to support the objectives stated for Test No. 3 in the original test matrix plan (see Table I-1 in Appendix I).

In this test seven (7) 1.5-meter long candles constructed of metal powder media were evaluated. This filter offer a number attributes that make them an excellent candidate for the Wabash HGF system. The filter is quite robust as it offers an extremely high media strength. In addition to this the powder bonds are much larger than the fiber diameter used in metal fiber media. This renders the filter much more capable of withstanding moderate amounts of corrosion. The type of candle used in this study had already accumulated run time in the commercial process. However, a number of improvements were incorporated into the construction of these candles. First, a media with slightly larger mean pore size was used. The filters were also modified using a special manufacturing technique that reduced the media pore size along the outer surface of the candle. In theory, this would help enhance the candle's surface filtration characteristics by restricting small particle migration into the filter substrate. By using a larger internal pore size the media pressure drop is reduced. This should result in higher blowback energy at the candle surface and yield a more effective cleaning.

The test was planned for 250 hours of syngas operation. The actual test lasted over 564 hours in duration. As in the previous test campaign, there were a number of instrument problems that came up and had to be addressed during the run. One of these problems resulted in an excessively high gas flow through the system for a brief period of time. However, the post-test inspection revealed that no char bridging had occurred between the filters as a result of this excursion.

The primary focus in this campaign was to study the blinding behavior of these new filters. The data could then be compared to blinding rates previously established for similar candles operating in the commercial process. Figure 4.2.5.1 shows the differential pressure across the filters as a function of time for the operating period. With the exception of a few instrument induced flow excursions, the system was maintained at a fairly constant gas flow rate with a filter face velocity set point of 2.5 fpm. Neglecting the first 50 hours of operation, the overall predicted life is approximately 1900 hours. However, if it is assumed that the candles were being conditioned for the first 300 hours of operation, a much better blinding curve is projected for the Slipstream filter. A fit of the data generated after the first 300 hours of operation yields a blinding life of around 3600 hours. This predicts a significant improvement in filter life but it still falls short of supporting the minimum time required for the process.

Test results also demonstrate that the robust construction of powder filters make it a reliable candle element. Long-term testing has also shown it to have a low rate of corrosion in the process.

A secondary objective in the study was to qualitatively evaluate the filtration efficiency of the candles. The qualitative method for evaluating filter efficiency is to study secondary filter resistance over the operating period. The V-160 resistance data shows a slight upward trend and suggests that there may have been a small amount of char getting through the filters. The data only provides a qualitative means of measurement. Isokinetic sampling would be required to quantitatively measure the inefficiency of these candles. However, this leakage would likely be in the acceptable range and should not pose a problem in the process.

Given that the blinding rate is relatively high, no further evaluations were made for this type of filter.

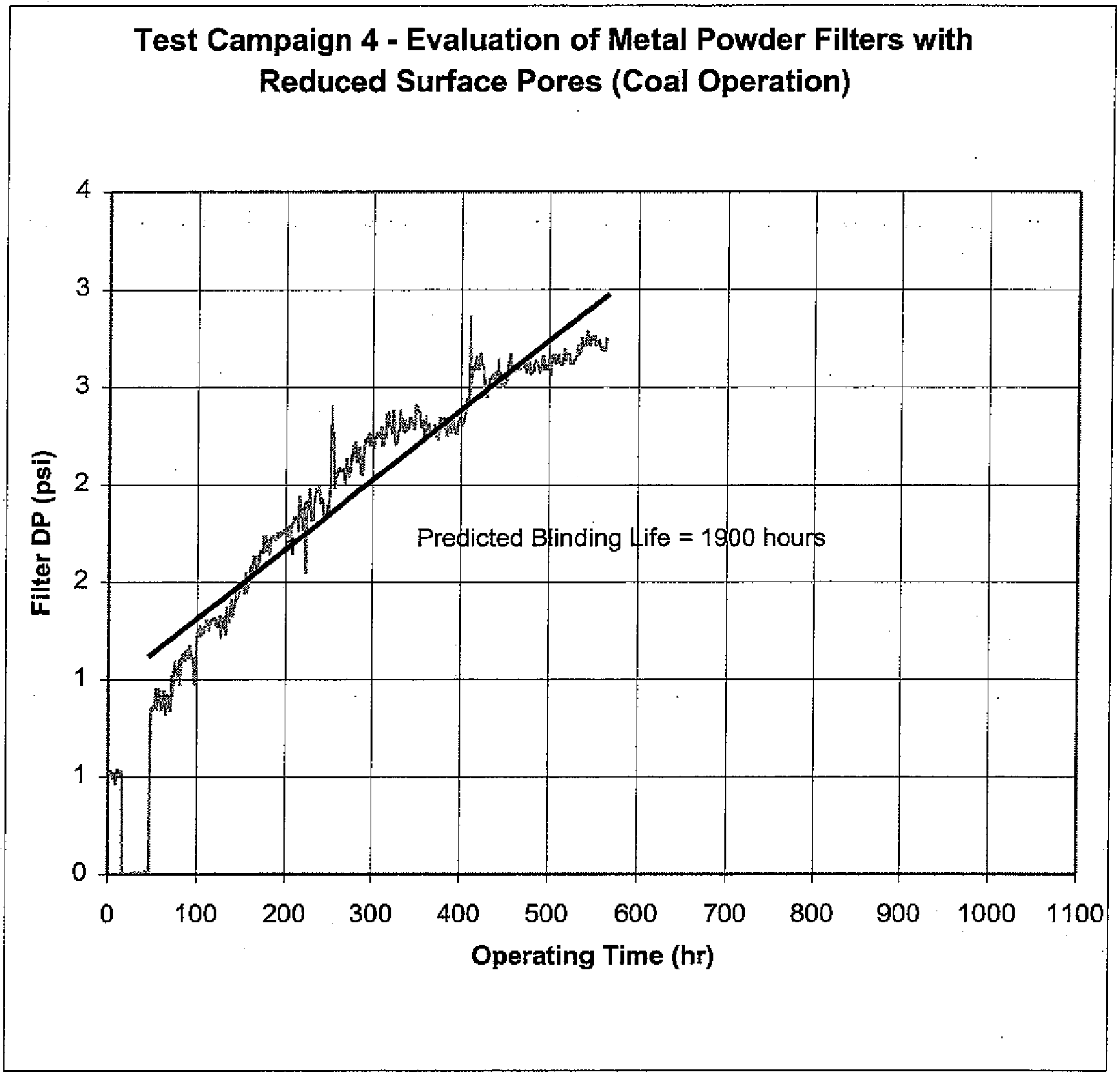


Figure 4.2.5.1: Test Campaign 4: Evaluation of Metal Powder Filters with Reduced Surface Pores (Coal Operation)

4.2.6 Test Campaign 5 (6/14 to 6/27/98)

The fifth Slipstream test was structured to support objectives stated for Test No. 8 in the original test matrix plan (see Table I-1 in Appendix I).

In this test, seven (7) 1.5-meter long clay-bonded silicon carbide candles were operated in the Slipstream to study blinding behavior and evaluate their reliability. The test was planned for 250 hours of operation. The actual time on syngas was just over 239 hours. It was concluded early due to a major plant outage.

The evaluation's primary goal was to confirm that these candles could be used as a competitive alternative to the original ceramic filters used at the facility. WREL has an ongoing interest in developing a reliable ceramic filter as a low cost alternative to metal candles. Ceramic filters have several distinct advantages. They demonstrate excellent corrosion resistance in the process and are typically about half the cost of a metal candle. A major concern with this filter is its susceptibility to cracking (low fracture toughness) both during maintenance handling and operation. Cold flow studies involving clay-bonded silicon carbide candles had indicated that a reduction in membrane pore size could provide a much lower rate of blinding. The candles involved in this study were similar to the OEM ceramic filter in that they both utilized a 15-micron mean pore size membrane. This evaluation was the first part in a series of studies aimed at validating the theory of smaller pore size providing better blinding rates in clay-bonded silicon carbide filters. It was the first step in working with this particular supplier to develop a reduced pore size membrane. In this study the supplier's standard membrane was evaluated.

Figure 4.2.6.1 shows the blinding trend established over the operating period. As expected, the blinding life for this candle was quite low. The trend yields a predicted blinding life of just over 1150 hrs. The Slipstream data shows that these filters closely follow the blinding behavior of a similar type of candle (OEM) that operated in the commercial HGF. The general agreement in both Slipstream and commercial HGF blinding trends confirms the Slipstream as a useful tool for predicting filter life in the commercial process.

Assuming that the filters were being conditioned over the first 150 hrs of the test, the blinding life is slightly improved. However, the predicted life still remains well below the minimum acceptable filter life for the WREL HGF. The blinding data shows that these candles are incapable of providing an acceptable period of sustained operation. For this reason they would not be a candidate for the WREL commercial HGF.

SEM analysis of a previously operated 15-micron mean pore membrane filter showed a complete penetration of char through the membrane layer. Similar analysis of 10-micron mean pore membranes showed only slight char penetration into the first or second pore layer of the membrane. The ingress of char into the larger pore membrane is a major contributor to the high rate of blinding in these filters. The blinding behavior demonstrated by this candle is more characteristic of a depth type filter. Consequently, the supplier was asked to reduce the membrane mean pore size to enhance the filter blinding characteristics. This evaluation of this new membrane was conducted in Test Campaign 9.

There was no evidence of solids breaking through the candles during the post-test inspection. There was no appreciable increase in V-160 backup filter resistance for the campaign. The overall filter efficiency appears to be within the acceptable range for the commercial process.

During the post-test inspection solids bridging was found in one area of the filter cluster that extended over half the length of the candles. There was no indication of damage to the filters as a result of this. The bridging likely started around 58 hours into the campaign as shown by the steep increase in filter differential pressure. This coincides with a plant trip at which time the Slipstream was taken off-line. The bridging probably occurred as it was taken off-line or when it was placed back in service. If this were the case, the filters operated for 180 hrs with some degree of solids bridged between them. Given that there were no failures in this campaign, the results would indicate these filters have sufficient strength to withstand some of the forces generated by solids bridging. This data suggests that the filter would provide an acceptable level of robustness in the process given a filter restraint system is used.

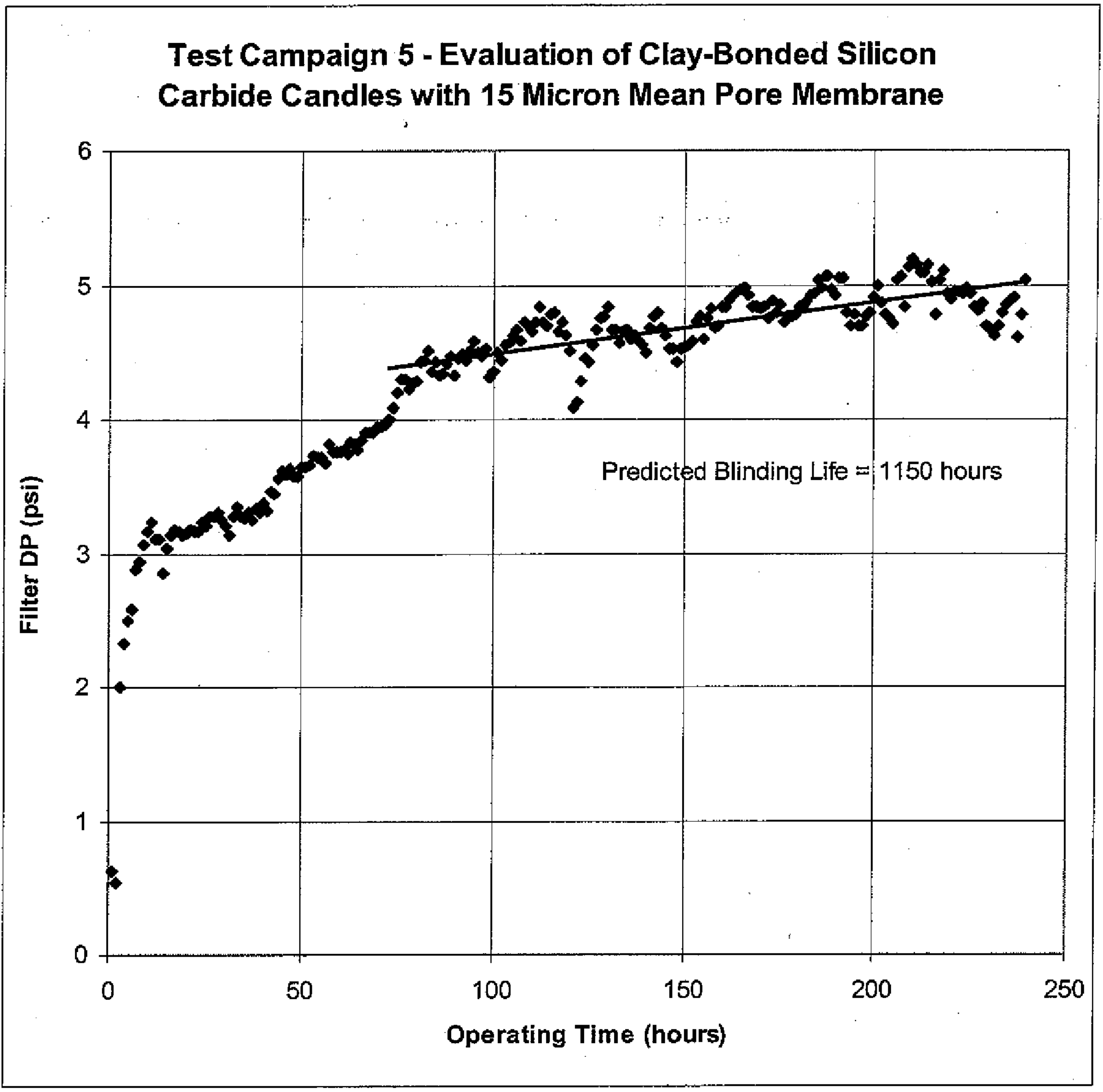


Figure 4.2.6.1: Test Campaign 5: Evaluation of Clay-Bonded Silicon Carbide Candles with 15 Micron Mean Pore Membrane

4.2.7 Test Campaign 6 (8/17 to 10/11/98)

The sixth Slipstream test was structured to support the objectives stated for Task 3 Test No. 7 in the original test matrix plan (see Table I-1 in Appendix I).

In this test, seven (7) 1.5-meter long clay-bonded silicon carbide candles with a 5 micron mean pore membrane were evaluated for blinding behavior and service reliability. The filters involved in this study were procured from the Wabash HGF OEM. The test was planned for 500 hours of syngas operation. The actual test duration was 375 hours. It had to be terminated early due to a major plant outage.

Initial screening of ceramic candles identified this filter as a potential candidate to provide an optimum rate of blinding in the process. The initial investigation took place in both the cold flow unit and the commercial HGF system. A number of clay-bonded silicon carbide candles with membranes ranging from 5 – 15 micron mean pores size were tested and in both evaluations the 5 micron membrane showed the lowest increase in resistance. However, the data was limited. The HGF evaluations only provided a starting and final filter resistance. The evaluation was conducted with a mix of filters in the commercial HGF that were known to have a wide variation in permeability. This can have a significant affect on blinding rate. The more permeable filters will have a much higher face velocity immediately after the blowback cycle. The magnitude of this "instantaneous" face velocity has a direct affect on the formation and permeability of the residual char layer. In most barrier type filters the residual char layer is the controlling factor that changes the overall filter resistance. Altering the parameters that go into the formation of this layer can lead to unreliable results. Consequently, it's impossible to establish an accurate rate of blinding when mixing filters in the commercial HGF. Using the Slipstream, a reliable trend is generated that accurately predicts filter behavior in the commercial process.

Figure 4.2.7.1 shows the filter pressure drop as a function of time for test period. The data predicts a filter blinding life of better than 11,400 hours of operation. The conclusion from this study is that the candle is fully capable of providing an acceptable period of sustained operation and therefore it would be a viable candidate for the Wabash HGF.

SEM analysis of this filter showed an absence of char penetration into the membrane layer. Both the SEM results and the low rate of blinding demonstrates that this candle exhibits excellent surface filtration characteristics.

The HGF at Wabash originally operated using ceramic candles. In this configuration the candles are fixed in a tubesheet that separates the clean gas plenum from the "dirty" side of the vessel. They were rigidly held in the tubesheet at the head of the candle. Other than the fixed headpiece, they were free hanging and had no means to restrain bottom side-to-side movement. Numerous failures occurred from flow induced movement at the bottom of the candles. In many cases, this was evident by localized areas of spalling at the extreme lower end of the candles. Consequently, a more robust and reliable ceramic filter restraint system needed to be developed. A key consideration for this system is that it only restricts candle movement. They should not rigidly be held in place. It's extremely important that the filter be able to move to a limited degree with thermal transients in the system. The OEM for the Wabash HGF provided several designs for a new type of filter support mechanism. Both were dimensionally modified for the study. Post-test inspections revealed leakage through one of the candle filter headpiece gaskets. A possible cause for this was that solids may have jammed between the bottom restraint device and filter forcing it upward. In theory, this could relax compression in the filter gasket. The exact root cause is of little consequence since the study showed the other the restraint system to be superior to any previously evaluated at the Wabash facility. The benefits of this system are that it's less costly to fabricate, less time consuming to install and provides only a restriction of side-to-side movement. It has proven to be a highly reliable bottom restraint system that does not promote solids bridging. The next step in the evaluation process was to scale it up for a test in the commercial hot gas filter system.

The backup filter, V-160, had a slow rise in differential pressure over the course of the test period. This likely resulted from the small amount of char that leaked by the filter gasket.

Neglecting the contribution in resistance from the gasket leak, the overall filter efficiency of the 5-micron mean pore filter appears to be within the acceptable range.

The filters and restraint system used in this study were evaluated in the commercial process later that year. A new fail-safe device was also tested along with them. The restraint system was proven to be equally as reliable in the commercial process.

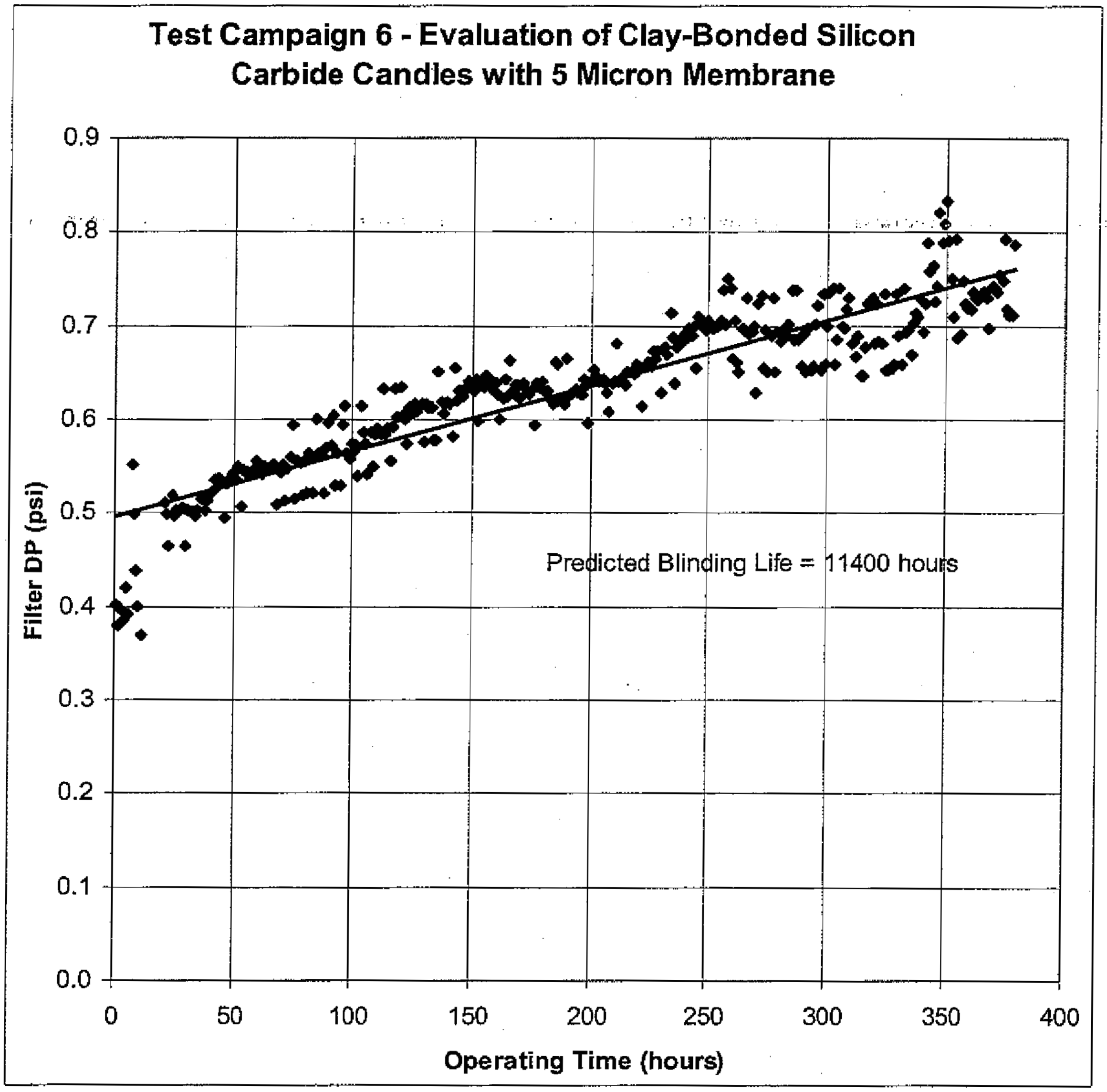


Figure 4.2.7.1: Test Campaign 6 - Evaluation of Clay-Bonded Silicon Carbide Candles with 5 Micron Membrane

4.2.8 Test Campaign 7 (10/17 to 11/5/98)

The seventh Slipstream test was structured to support the objectives stated for Test No. 5 in the original test matrix plan (see Table I-1 in Appendix I).

In this test, seven (7) 1.5-meter sintered powder iron aluminide alloy candles were operated in the slipstream unit to study blinding behavior and service reliability. The test was planned for 250 hours of syngas operation. The actual test duration was just over 423 hours.

In certain applications, porous iron-aluminide filters have demonstrated excellent resistance to high-temperature corrosion in H_2S rich gas streams similar to the Wabash gasification process. Based on these results, a program was established at the Wabash facility to evaluate iron-aluminide materials for hot gas filtration. The evaluation would seek to determine life limitations imposed by both corrosion and blinding in the porous media. The initial screening was conducted in the commercial HGF. In this evaluation, the iron aluminide media showed an acceptable rate of corrosion. However, there was some suspicion that blinding might be a problem. Due to the large number of filters within the commercial vessels, it is impossible to evaluate a small set of test elements and collect meaningful blinding data. This part of the study was better suited for the Slipstream system. A cluster of seven (7) iron-aluminide candles was operated in the slipstream for just over 423 hours. Figure 4.2.8.1 shows the filter pressure drop as a function of time over the operating period. The established blinding trend yields a life prediction of 10,138 hours. The blinding data would indicate these filters are viable candidates for the commercial process. However, long-term corrosion studies in excess of 5000 hours were required to establish a predicted filter corrosion life. This study was conducted in the commercial HGF.

Filters from both the HGF and Slipstream studies were examined by Oak Ridge National Laboratories (ORNL) to investigate both blinding and corrosion. These findings are summarized in a paper prepared by ORNL that is included as Appendix II. To summarize, the general mode of media blinding is caused by a formation of iron sulfide (Fe-S) that grows into and eventually fills the media pores. This process accelerates as exposure time is increased. In addition to this, the filters were found to maintain their original strength as long as the Fe-S formation did not occlude more than about 50% of the pores. Some iron aluminide media samples demonstrated a corrosion life near the acceptable limit . However, a number of samples did not. The study results show that the higher chromium iron aluminide exhibits a better resistance to process induced corrosion. At this point, the media tested here does not reliably demonstrate a corrosion rate that could sufficiently support the required HGF operating times. Subsequent development efforts should focus on evaluating the higher chromium iron aluminide filter media.

Metal powder fail-safes operating in the filters for this study did not see any appreciable increase in resistance over the duration of the campaign. Based on this data, fail-safe blinding when used with iron-aluminide filters is not a concern. One fail-safe did suffer a fracture along the longitudinal weld seam during operation. The vendor determined that this was caused by a problem in the application of the longitudinal weld. As a result, better QA/QC processes were implemented to successfully prevent this type of failure in future applications.

There was a slight increase in the backup filter (V-160) resistance over the course of this campaign. However, the inefficiency in these filters was deemed insignificant.

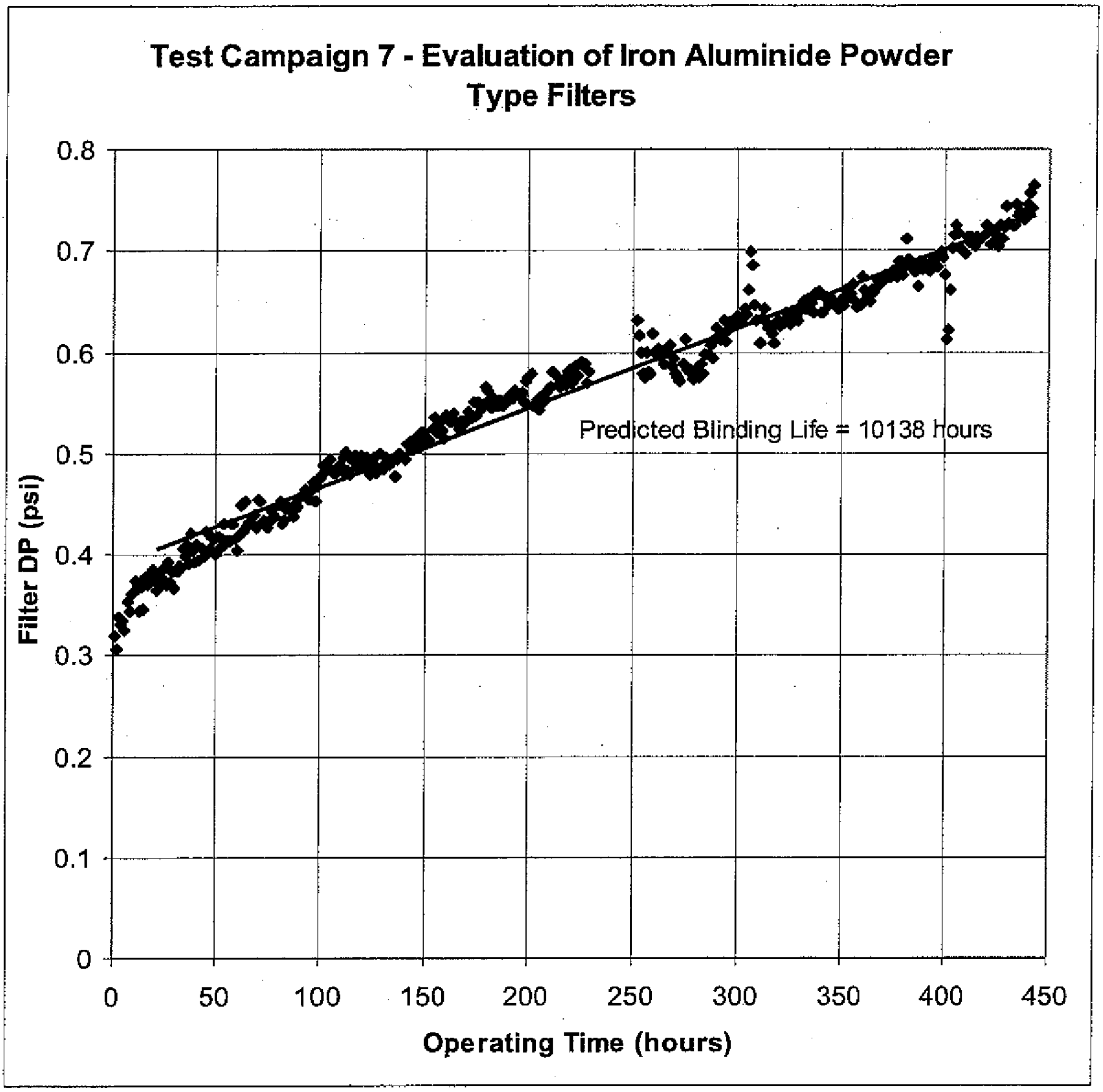


Figure 4.2.8.1: Test Campaign 7 - Evaluation of Iron Aluminide Powder Type Filters

4.2.9 Test Campaign 8 (1/12 to 1/19/99)

The eighth Slipstream test was structured to support objectives listed for Test No. 9 in the original test matrix plan (see Table I-1 in Appendix I).

In this test, seven (7) 1.5-meter long candles constructed of metal fiber media were evaluated in the slipstream unit. Corrosion evaluations in both the slipstream and commercial processes had identified a new media alloy as a potential candidate to improve filter life. Results indicate that the media could last two to four times longer than those currently utilized in the commercial system. Due to the difficulty in manufacturing this media, the fiber diameter is slightly larger than the type used in a previous evaluation (see Test Campaign 3). A primary focus in this study was to evaluate blinding in the new media. A second objective was to evaluate a new hardware configuration to fix the filters in the vessel tubesheet. The new design offers several distinct advantages over the existing filter fixing system. A third objective was to qualitatively evaluate the filtering efficiency of the new media.

Up to this point, metal fiber filters provided the best operating life in the commercial HGF. They have been proven to be highly reliable in this system. Corrosion testing of new alloys has shown the media selected for the study to be highly resistant to attack from the process gas. In addition to the alloy material change, a significant difference in this media is the larger fiber diameters used for its construction. The net result is an increase in media porosity and it was this change that made the blinding evaluation a key element of the study. Several prototype medias were constructed from the new alloy fibers specifically for testing in the Slipstream unit to obtain a recipe that yielded optimal rates of blinding.

The first proto-type media study was planned to be 250 hours in duration. However, 3 of the 7 filters failed after 158 hours of operation forcing the study to be terminated early. Fortunately, enough data was generated to establish a blinding trend for these filters. Figure 4.2.9.1 shows the filter differential pressure as a function of time over the operating period. Using a linear regression fit of the data a 2478-hour life is calculated for these filters. This falls short of the required mean time between HGF filter maintenance outages. Based on the study results, it was concluded that this media recipe could not provide an acceptable filter life in the HGF.

During this study, a new hardware configuration to fix the candles within the vessel tubesheet was evaluated. The new design utilized a filter headpiece with parallel machine threads to fasten it into the tubesheet. Redundant gasket seals were incorporated to prevent solids leakage into the clean side of the tubesheet. The parallel threads helped eliminate galling problems experienced in many of the existing fasteners. The current filter fastening hardware configuration requires a significant number of man-hours to replace the candles. One of the major benefits inherent to this design is that it drastically reduces the man-hour requirement for this effort. Study results showed that the redundant gasket seals were quite effective at preventing solids from leaking into the clean side of the system. Candle filter installation and removal processes were significantly improved by utilizing this new system. The study helped to initiate further development work to incorporate an easily removable fail-safe device into the design.

Given the increased porosity of these filters, another objective was to qualitatively evaluate their solids removal efficiency. Due to the new hardware configuration, no fail-safes were used in this evaluation. A faulty instrument caused a number of V-160 resistance measurement problems during the campaign but enough data was collected to evaluate filtration efficiency. The overall trend for V-160 resistance shows that there was minimal char getting through the filters prior to the failures. This data indicates that the new media will provide sufficient filtration efficiency for the process.

Investigation into the filter weld failures identified a problem in the manufacturing process. Implementation of an improved manufacturing procedure has sufficiently resolved this problem.

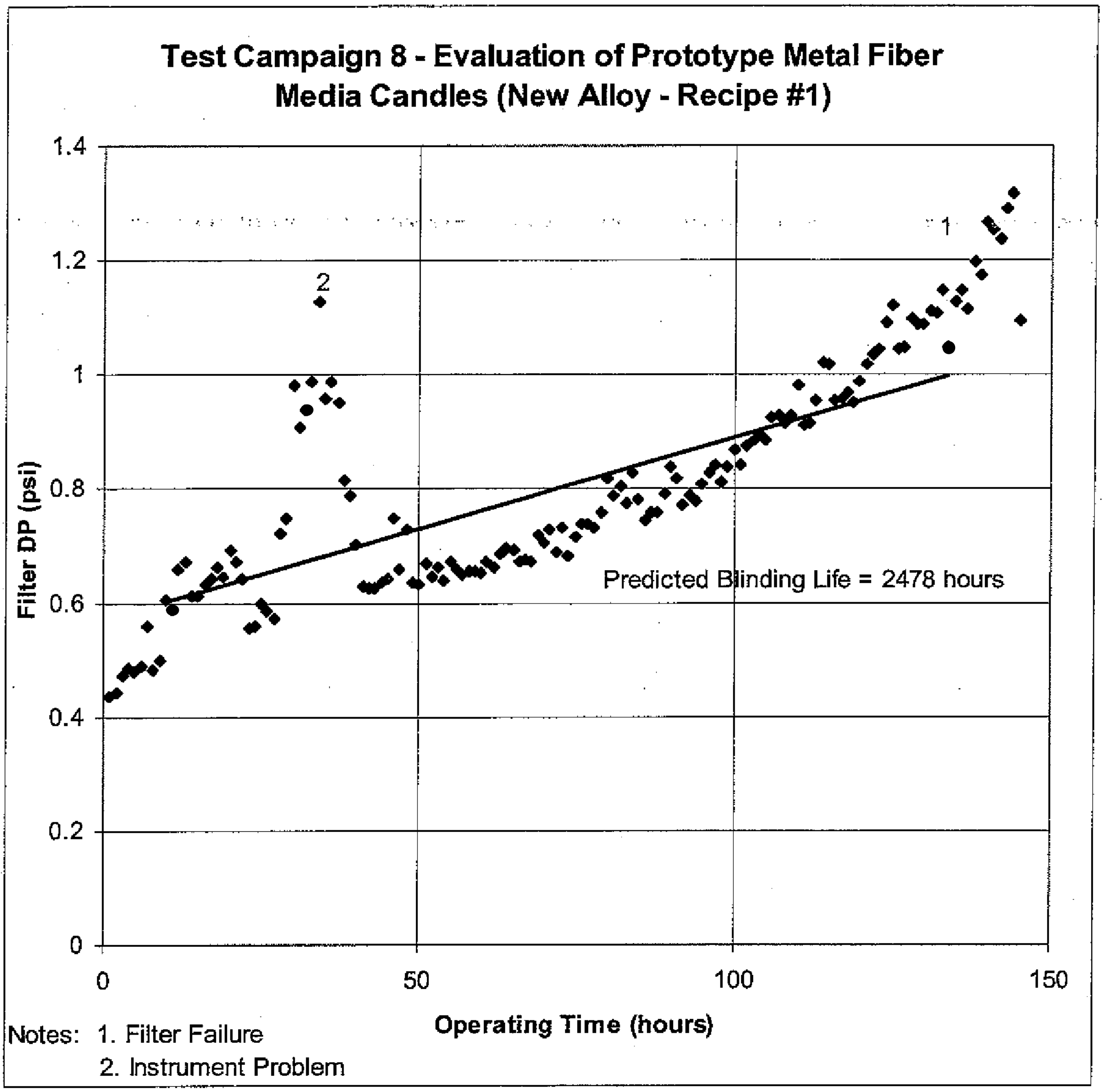


Figure 4.2.9.1: Test Campaign 8 - Evaluation of Prototype Metal Fiber Media Candles (New Alloy - Recipe #1)

4.2.10 Test Campaign 9 (2/15 to 2/25/99)

The ninth Slipstream test was structured to support the objectives stated for Test No. 6 in the original test matrix plan (see Table I-1 in Appendix I).

For this test, seven (7) 1.5-meter long clay-bonded silicon carbide candles constructed using a new proto-type membrane were operated in the slipstream unit to study blinding behavior and evaluate service reliability. These filters were from the same supplier as those evaluated in Test Campaign 5. The only difference was a reduction in the mean pore size of the membrane layer. The test was planned for 250 hours of syngas operation. The actual test duration was just over 235 hours. Early termination was due to a major plant outage.

A similar filter evaluated in Test Campaign 6 had a predicted blinding life of over 11,400 hours. In Test Campaigns 5 and 6 filters were supplied by different manufacturers. They were similar in construction but differed in the pore size of the membrane layer. The mean pore sizes were 15 and 5 microns for Test Campaigns 5 and 6, respectively. The smaller pore size used in Test Campaign 6 produced a blinding life that was significantly better than the one generated in the previous campaign. Based on these results, this manufacturer developed a new prototype filter that included a reduction in the membrane pore size. The next step in this process was to evaluate the blinding characteristics of the new membrane. The main focus for this effort was to develop a competitive alternative to the OEM ceramic candle.

The primary objective was to develop a predicted blinding life for the new filter membrane. Figure 4.2.10.1 shows the filter differential pressure as a function for the test period. Neglecting the first 50 hours of operation, a linear fit of the data shows a predicted blinding life of 7256 hours. This falls short of the 11,400-hour life predicted for the 5-micron membrane filter in Test Campaign 6. To be considered a competitive alternative, the filters should have more comparable blinding rates. As a result, it's recommended that an additional reduction in membrane pore size be considered for this filter.

There was no appreciable gain in V-160 (backup filter) resistance during the study. Consequently, the overall efficiency of this filter is deemed acceptable for the Wabash process.

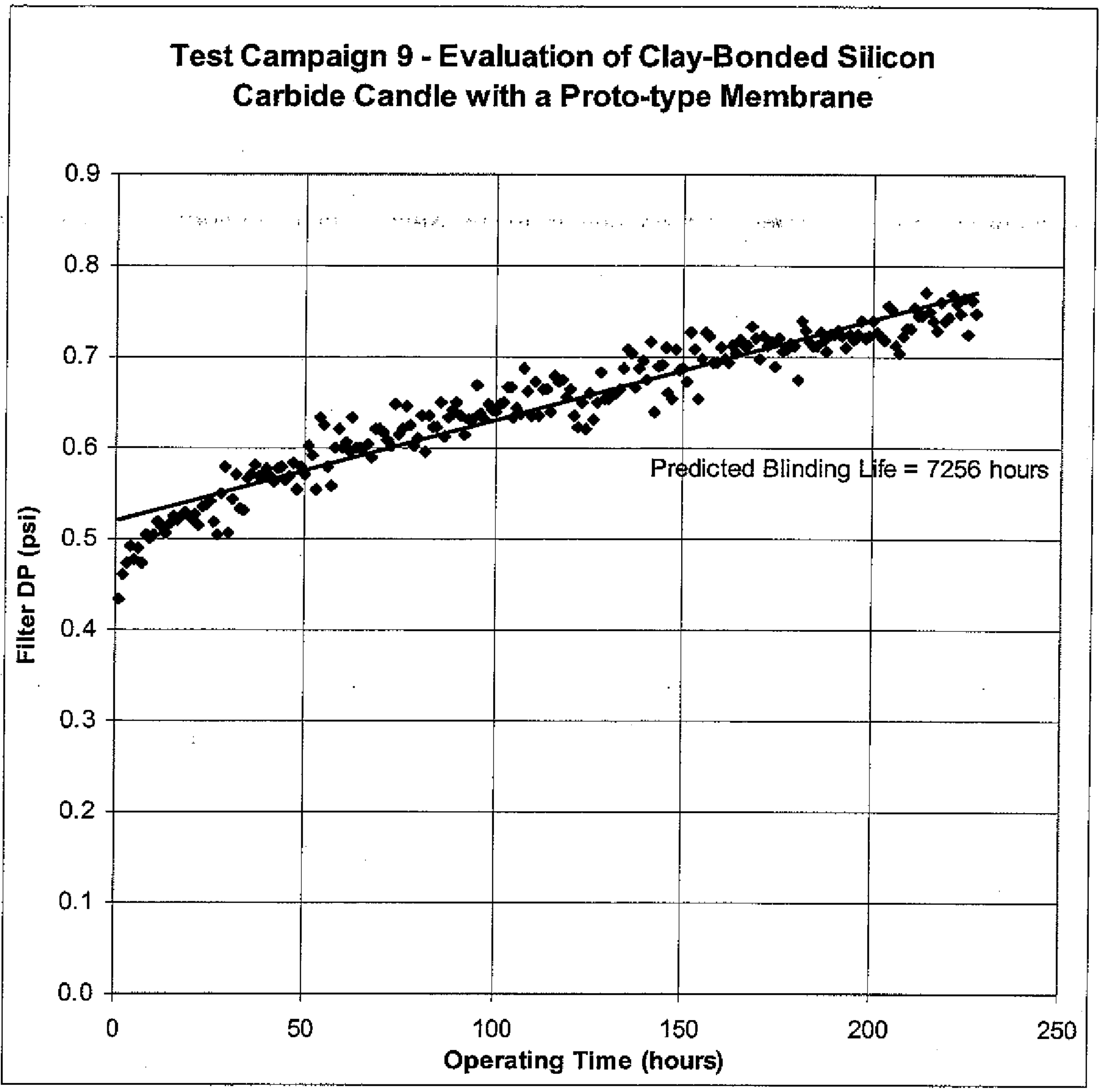


Figure 4.2.10.1: Test Campaign 9 - Evaluation of Clay-Bonded Silicon Carbide Candle with a Proto-type Membrane

4.2.11 Test Campaign 10 (6/28 to 7/10/99)

The tenth Slipstream test was structured to support the objectives stated for Test No. 10 in the original test matrix plan (see Table I-1 in Appendix I).

For this test, seven (7) 1.5-meter metal fiber media candles were evaluated in the slipstream unit. It was structured as a follow-up to Test Campaign 8 which had involved the study of a new media alloy and filter construction. The filters for this study used a second recipe for laying down the media fibers. The new design sought to improve the blinding characteristics of this new alloy media. Fabrication improvements were included to address the candle failures from Campaign 8. The test was planned for 250 hours of syngas operation. The actual test duration was just over 257 hours.

In Test Campaign 8 the predicted blinding life was significantly less than the "standard" fiber media evaluated for Test Campaign 3. The main objective in this study was to establish a blinding rate for the second recipe of new prototype media. Figure 4.2.11.1 shows the filter differential pressure as a function of time over the slipstream test period. The trend predicts a blinding life of over 10,170 hours for this filter. This is a significant improvement over the 2478-hour blinding life predicted in Test Campaign 8. The trend is more comparable to the one developed in Test Campaign 3. The 10,170-hour life prediction exceeds the minimum filter operating time required for the HGF performance objectives.

In Test Campaign 8 three (3) filters were found to have suffered failures during the study. Improvements were made in the manufacturing process to address the failures. The secondary objective in this study was to evaluate the effectiveness of these changes. There were no failures during the study. Post-examination of the candles showed them to be in excellent condition. It was concluded that the manufacturing improvements had adequately addressed the associated problems.

There was no appreciable gain in V-160 resistance for this study. Therefore, it's assumed that the media provides an acceptable level of filtration efficiency.

Based on the favorable results of this study, the filter evaluated here is deemed as an acceptable candidate for the Wabash HGF.

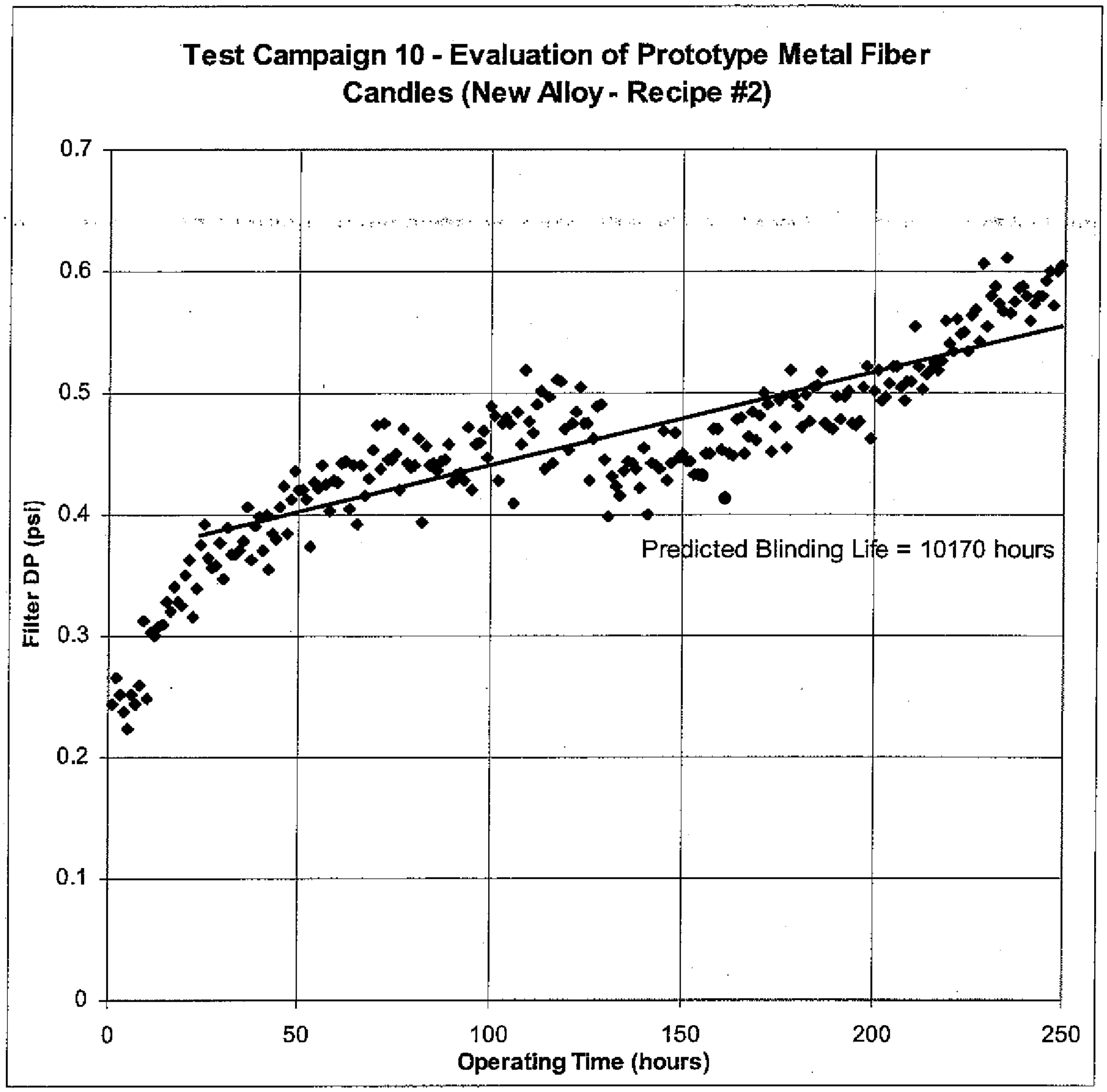


Figure 4.2.11.1: Test Campaign 10 - Evaluation of Prototype Metal Fiber Candles (New Alloy - Recipe #2)

4.2.12 Test Campaign 11 (8/13 to 8/14/99)

The eleventh Slipstream test was structured to support the objectives stated for Test No. 16 in the original test matrix plan (see Table I-1 in Appendix I).

For this test, seven (7) 1.5-meter long oxide composite candles were evaluated in the slipstream process. The test was planned for 250 hours of syngas operation. It had to be terminated early due to failures in the candle media.

This was the first evaluation of a ceramic composite type candle in the Wabash gasification process. The primary objectives were to predict blinding life and evaluate the candle's robustness in the process.

The campaign was terminated after 29 hours of operation due to an excessive amount of char leaking through the test filters. The post-test inspection revealed that several filters had suffered detachment of the outer layer at various locations along each candle. There was also damage in the filter substrate at some of these locations. Attrition of this fibrous structural material was likely caused by high gas flow in these areas following detachment of the filtering layer. This ultimately led to the rapid blinding seen in the backup filter. Due to the short duration of the study, a reliable blinding trend could not be established. Post-test samples were submitted to the supplier for evaluation. They showed the filter permeability to be approximately half of that for a new candle. This was said to be in the normal range for a candle exposed in similar processes. Filter strength was not evaluated due to the type of failure and short test duration. The vendor's conclusion was that the most likely cause of failure came from forces generated by the high pressure blowback gas. These forces were likely stronger than the bond strength between the filtering layer and the filter substrate. According to the supplier, this was not the first time a failure like this had happened during exposure in a gasification process. The results indicate that an improved method of construction is required to make them stronger and better suited for this and other gasification processes. It is interesting to note that all three monolithic membrane coated (SiC) ceramic candles evaluated in the slipstream system (Campaigns 5, 6 and 9) did not experience this type of problem. Consequently, design improvements for these filters should focus on achieving similar material bond strengths to those used in the clay-bonded SiC candles. Another potential solution might be to perform blowback optimization studies to potentially reduce the forces generated in the filter media. However, the results indicate that stronger more robust candles will need to be constructed to make them suitable for this and other gasification processes.

4.2.13 Test Campaign 12 (8/22 to 9/3/99)

The twelfth Slipstream test was structured to support the objectives stated for Test No. 17 in the original test matrix plan (see Table I-1 in Appendix I).

For this test, seven (7) 1.5-meter long oxide composite candles were evaluated in the slipstream process. This was the second evaluation of an oxide composite candle in the Wabash process. The test was planned for 250 hours of syngas operation. The actual test was 291 hours in duration.

The filters involved in this study were from a different supplier than the type used in the previous evaluation. However, the objectives were essentially the same as those for Test Campaign 11. According to the supplier, this was the first time a candle of this type had been operated in a gasification process. All previous studies by this manufacturer had been conducted in PFBC type applications. As in the previous slipstream study, the evaluation period was planned for 250 hours. The test period was extended since the end date fell near the weekend. After 290 hours of operation char began to leak through the candle filters.

Figure 4.2.13.1 shows the filter differential pressure as function of time for the campaign. The trend predicts a blinding life of 3,267 hrs. The results show these filters are incapable of supporting the required operating time for the commercial HGF. A reduction in the filtering layer pore size would likely be required to improve the blinding characteristics of this filter in the Wabash process.

The study had to be terminated due to char breaking through the candle filters and a resultant high V-160 resistance. Three of the seven candles involved in this study had suffered membrane damage in various localized areas. Spalling of the membrane layer resulted in solids leakage through the candle. Another candle was found to have suffered a separation (crack) at the base of the flange area (hemispherical head). Small cracks were present in the flange area as well. It's possible that the force exerted by the spring loaded mechanism used to hold the candles in the tube plate may have been greater than filter material strength. Either a stronger flange (more dense) or a different holding mechanism would be required for this filter to provide acceptable reliability in this process. It's interesting to note that three clay-bonded silicon carbide candles were evaluated using the same type of filter fixing system and had suffered no damage. As in the previous study, spalling of the membrane layer was likely a result of forces generated during the blow back event. It would seem that these forces are higher than the bond strength of the membrane layer to the filter substrate. The manufacturer also commented that a similar phenomenon occurred during testing at another gasification facility. Either a reduction in blowback forces or higher membrane bond strengths will be required to make this filter more reliable in gasification processes.

There was little evidence of char leaking by the candles until shortly before the test was terminated. This was evident in the V-160 backup filter resistance over the campaign. Based on this data, the filter efficiency is deemed sufficient for the process.

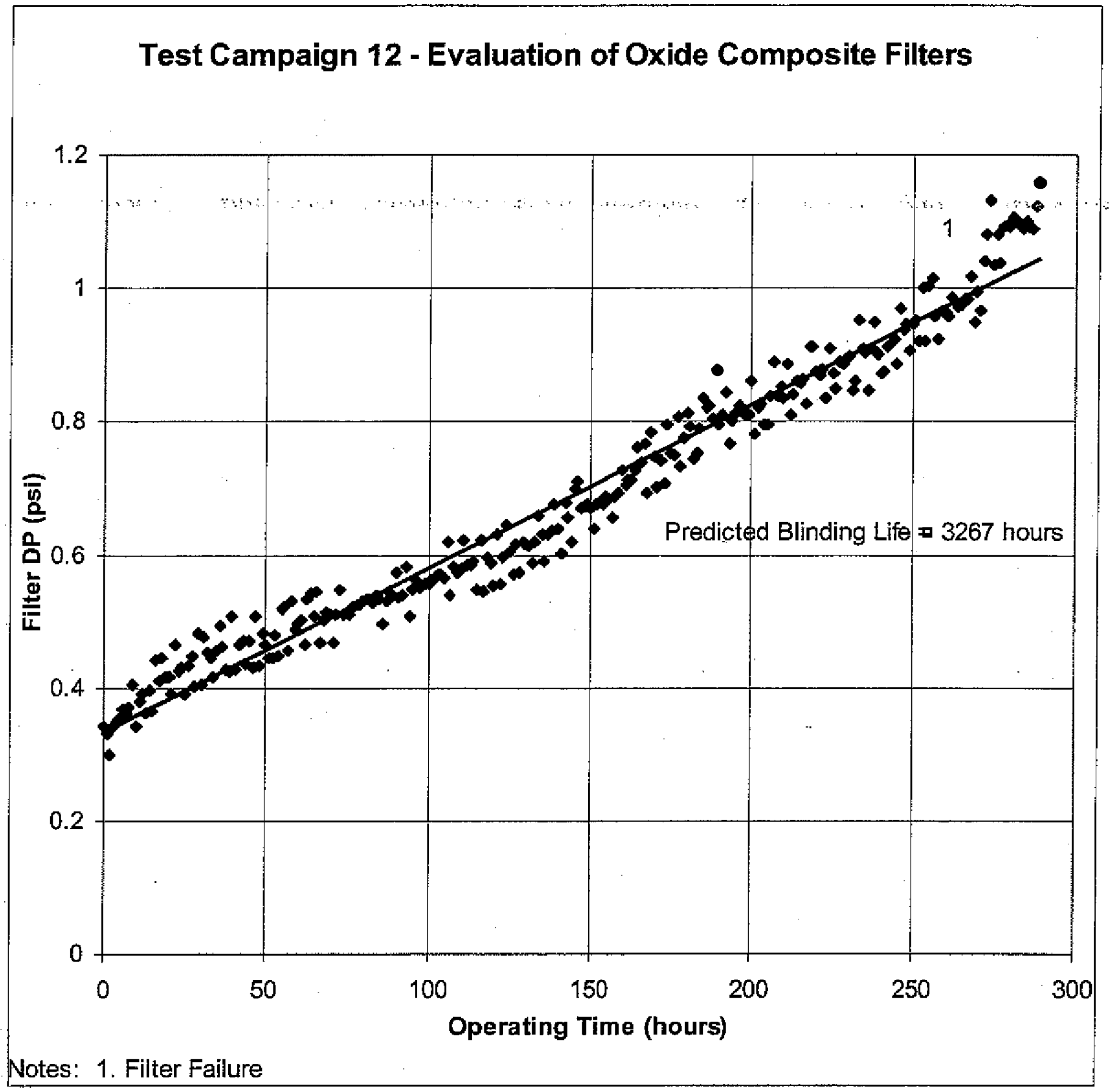


Figure 4.2.13.1: Test Campaign 12 - Evaluation of Oxide Composite Filters

4.2.14 Test Campaign 13 (9/14 to 9/28/99)

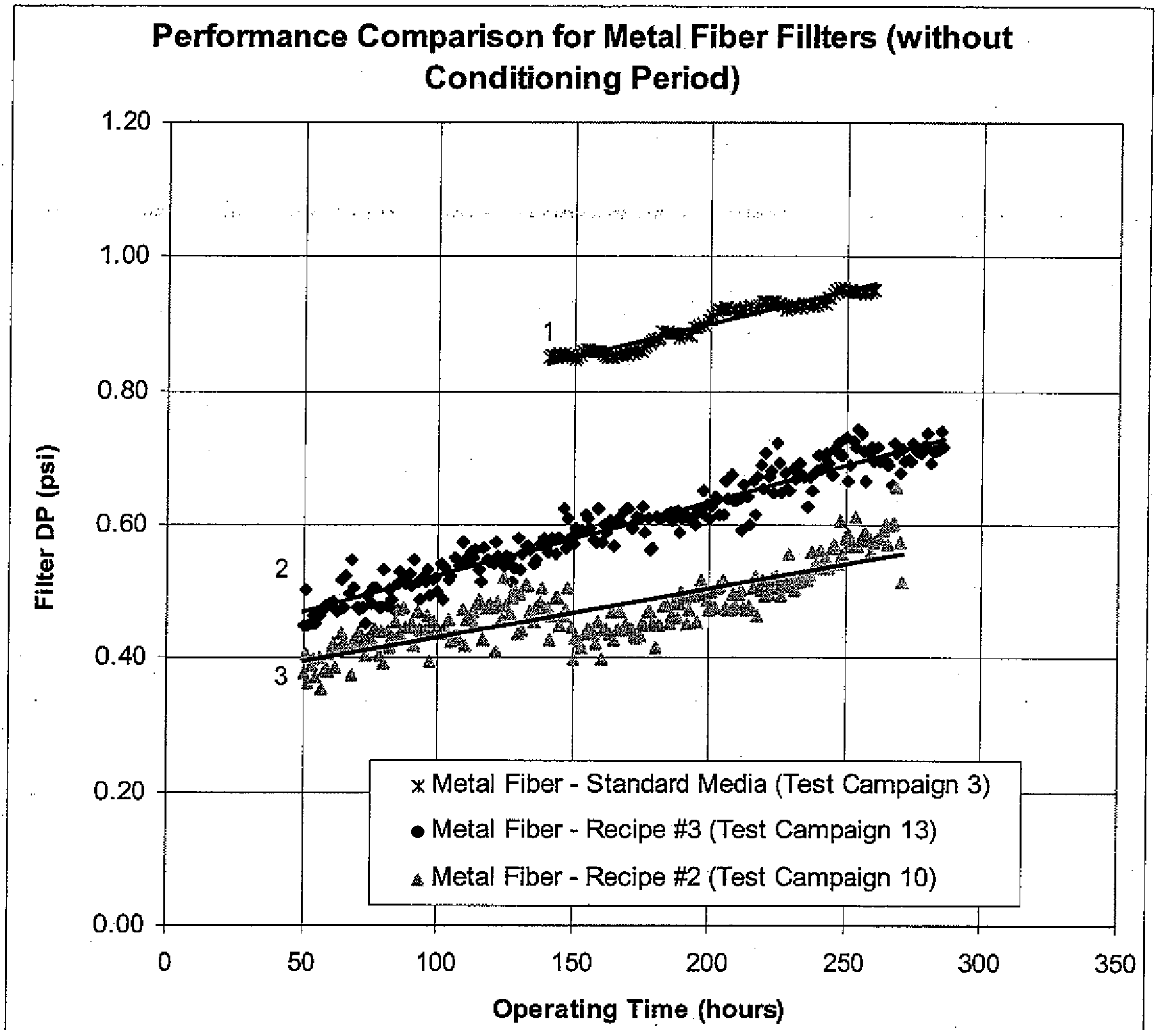
The Thirteenth Slipstream test was structured to support the objectives stated for Test No. 10 in the original test matrix plan (see Table I-1 in Appendix I).

For this test, seven (7) 1.5-meter long candles constructed of metal fiber media were evaluated in the slipstream unit. It was a follow-up to Test Campaigns 8 and 10 where a new media alloy and filter construction were being studied. The only change in these filters was a new recipe for laying down the media fibers. The alteration was made in an attempt to further enhance the blinding characteristics of the filter used in Test Campaign 10. The test was scheduled for 250 hours of syngas operation. It lasted 300 hours in duration.

The filters for this study were constructed with a new media alloy being evaluated for use in the commercial vessels. The primary objective of this study was to evaluate the blinding characteristics for the new media recipe. Figure 4.2.14.1 shows the filter differential pressure as a function of time over the test period. A linear fit of the data predicts a filter blinding life of 7,350 hours. This rate is within the acceptable level required for the WREL HGF. From a blinding standpoint, this filter demonstrates good performance and would be suitable for the WREL process. Also shown on Figure 4.2.14.1 are the three media recipes tested using this new alloy. The data clearly shows that the recipe (#2) used in Test Campaign 10 offers the best blinding life.

Over the course of the study there was no appreciable gain in backup filter resistance. Consequently, the filtration efficiency for these candles is deemed to be within the acceptable range for the WREL process.

The test concluded a series of studies (also see Test Campaigns 8 and 10) aimed at developing a new alloy filter that would ultimately serve as an upgrade to the "standard" candle filter used at the Wabash facility. When compared to the standard media, the new alloy provides nearly twice the corrosion life and has equally as good or better blinding characteristics. In the early stages of development, problems in fabrication were recognized and corrected. As result the filter has proven to be highly reliable in the commercial process. Along with this effort a new configuration was developed for fixing the filters within the vessel tubesheet. The changes also incorporate an improved system for holding fail-safe devices within the filters. The improvements have significantly increased filter life and greatly reduced the overall maintenance time required for the commercial HGF.



Note: 1. Metal Fiber - Standard Media Predicted Blinding Life = 7780 hours (Test Campaign 3)
2. Metal Fiber - Recipe #3 Predicted Binding Life = 7350 hours (Test Campaign 13)
3. Metal Fiber - Recipe #2 Predicted Binding Life = 10200 hours (Test Campaign 10)

Figure 4.2.14.1: Performance Comparison for Metal Fiber Filters (without Conditioning Period)