Coking.com Best Practices Seminar

Recent Advances in Delayed Coker Heater Technologies to Extend Run Lengths and Reduce Tube Metal Temperatures

April 8,9,10, 2003

Presented by

William C. Gibson, President of
Petro-Chem Development Co., Inc.

Petro-Chem Development Co., Inc.

Petro-Chem Development Co., Inc. offers the refining and petrochemical industries a unique and extensive line of heat transfer equipment and services. Petro-Chem is the world's largest independent fired heater company with markets throughout the world.

3

Two coking mechanisms dominate the internal fouling rates in delayed coker heaters

- Bulk cracking
- Film cracking

Petro-Chem Development Co., Inc.

4

Two Coking Dominant Mechanisms

- Bulk Cracking
  - Normal or conventional coker heater analysis is based on bulk cracking models
- Bulk Cracking Design – Rules of Thumb
  - Increase average radiant flux to minimize the bulk fluid residence time above 800°F
  - Fluid mass velocities above 350 lb/Ft^2 Sec
  - Clean pressure drop above 300 psi
- Bulk Cracking Design Philosophy has been the Primary Driver in recent moves to Double Fired Delayed Coker Heaters
  - Single fired, 9000 BTU/Hr-Ft^2 average radiant flux rate = 16,200 BTU/Hr-Ft^2 peak radiant flux rate
  - Double fired, 13500 BTU/Hr-Ft^2 average radiant flux rate = 16,200 BTU/Hr peak radiant flux rate

Petro-Chem Development Co., Inc.

Two Coking Dominant Mechanisms

- Film cracking - TRANSACTIONS OF THE ASME

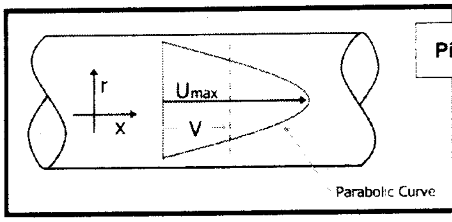
"There is another type of decomposition produced in heaters, "Film Cracking", which is independent of mass decomposition and which occurs when the film is overheated because of higher heat inputs to the tubes than the charge can absorb. Film cracking can occur below temperatures of mass decomposition and may become serious where evaporation in the heater (two phase flow) forms a viscous emulsion of vapors and liquid with liquid as the outer phase. Film cracking, occurring when the charge is above the temperature of initial decomposition, may cause heavy coke deposits in the tubes and premature shutdown of the heater. A well designed heater not only must produce the desired time-temperature effects (bulk cracking analysis) but do this with linear and mass velocities and vaporization in the tube which will produce a sufficiently turbulent flow to tear up the film so that even if it is overheated temporarily or locally it is quickly quenched in the main flow."

Film Cracking

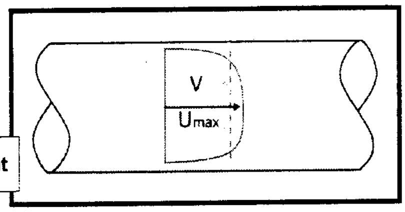
- The primary cause of elevated rates of tube side fouling
- Primary design variables influencing film cracking:
  - ✓ Flowing conditions at the tube wall
  - ✓ Peak radiant flux
  - ✓ Asphaltenes
  - ✓ Pressure
  - ✓ Bulk fluid and film temperature
  - ✓ Cracked heavy gas oil (CHGO) recycle rates and composition
  - ✓ Inside heat transfer rate

Film Cracking

- Flowing conditions at the tube wall



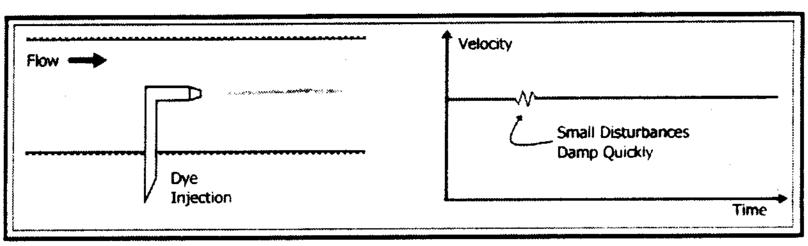
Pipe Flow Velocity - Laminar



Pipe Flow Velocity - Turbulent

Film Cracking

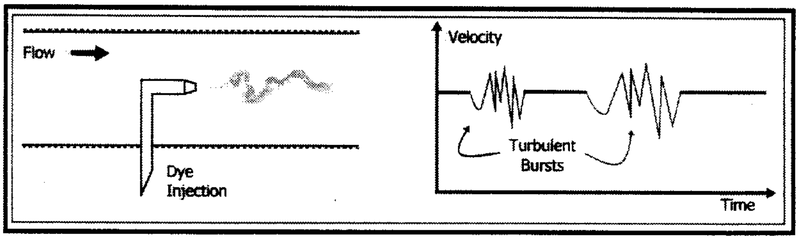
- Flowing conditions at the tube wall (cont.)



Dye Streak Visualization and Velocity Measurements – Laminar Flow

Film Cracking

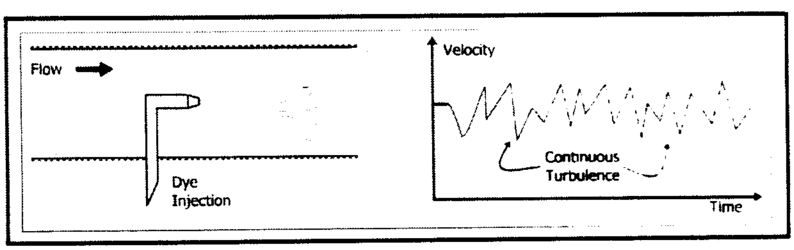
- Flowing conditions at the tube wall (cont.)



Dye Streak Visualization and Velocity Measurements – Transition Flow

Film Cracking

- Flowing conditions at the tube wall (cont.)

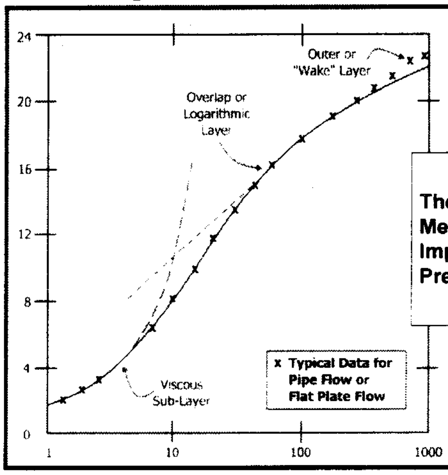


Dye Streak Visualization and Velocity Measurements – Turbulent Flow

11

Film Cracking

- Flowing conditions at the tube wall (cont.)



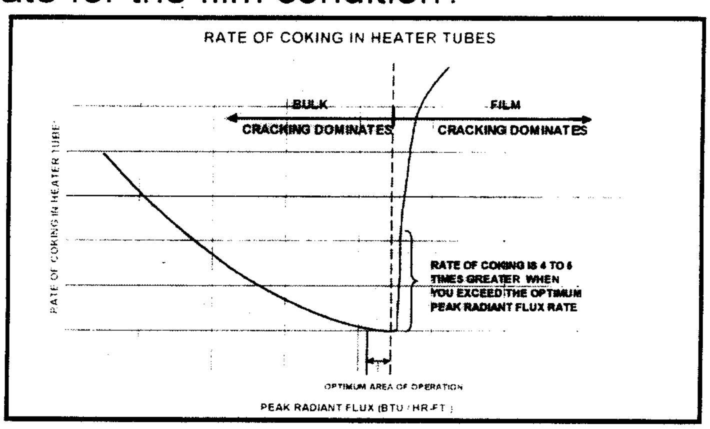
The Law-of-the-Wall for Turbulent Mean Flow Past a Smooth, Impermeable Surface with Modest Pressure Gradient

Petro-Chem Development Co., Inc.

12

Film Cracking

- What is the allowable peak radiant flux rate for the film condition?



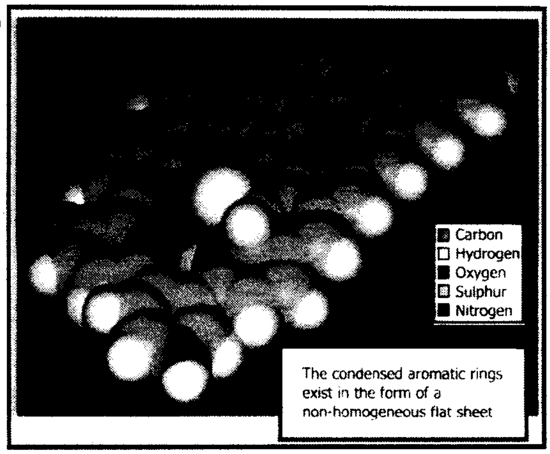
DON'T FALL OFF THE CLIFF ! ! !

Petro-Chem Development Co., Inc.

13

Film Cracking

- Asphaltenes



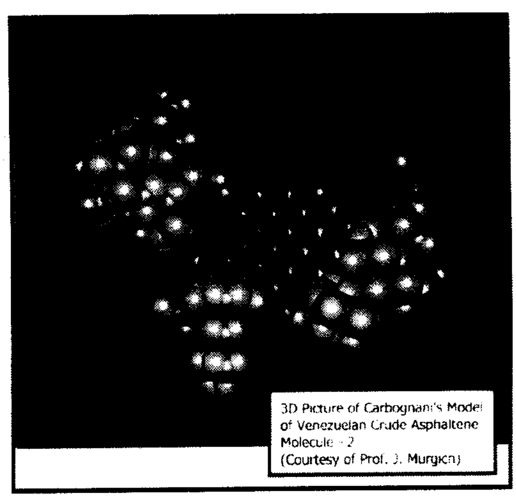
The condensed aromatic rings exist in the form of a non-homogeneous flat sheet

Petro-Chem Development Co., Inc.

14

Film Cracking

- Asphaltenes



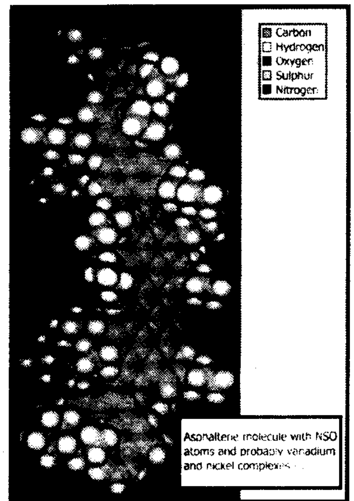
3D Picture of Carbognani's Model of Venezuelan Crude Asphaltene Molecule - 2
(Courtesy of Prof. J. Murgich)

Petro-Chem Development Co., Inc.

15

Film Cracking

- Asphaltenes



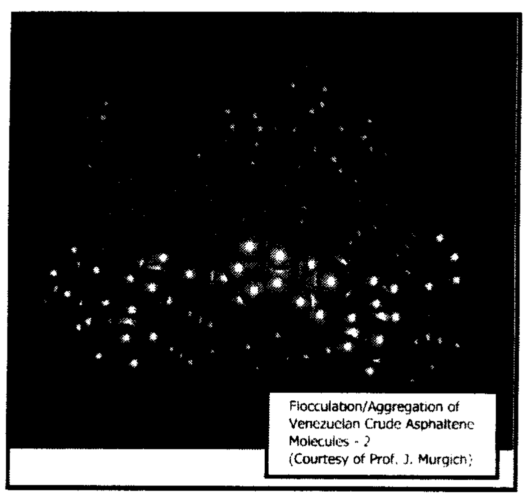
Asphaltene molecule with NSO atoms and probably vanadium and nickel complexes

Petro-Chem Development Co., Inc.

16

Film Cracking

- Asphaltenes

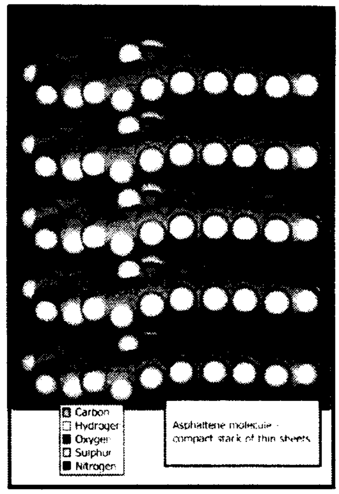


Flocculation/Aggregation of Venezuelan Crude Asphaltene Molecules - 2
(Courtesy of Prof. J. Murgich)

Petro-Chem Development Co., Inc.

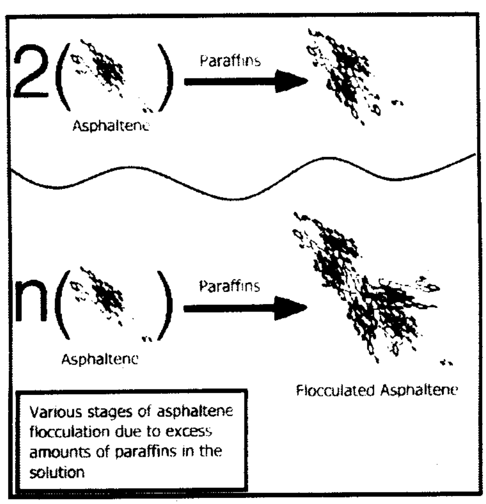
Film Cracking

- Asphaltenes



Film Cracking

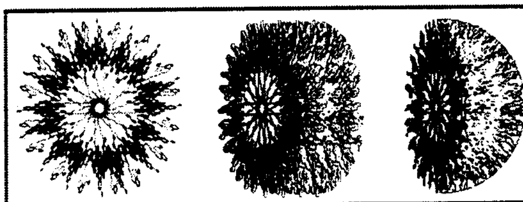
- Asphaltenes



19

Film Cracking

- Asphaltenes



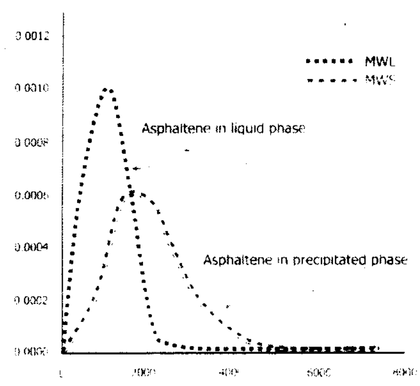
Various shapes of asphaltene micelles formed in the presence of large amounts of polar or aromatic solvents

Petro-Chem Development Co., Inc.

20

Film Cracking

- Asphaltenes



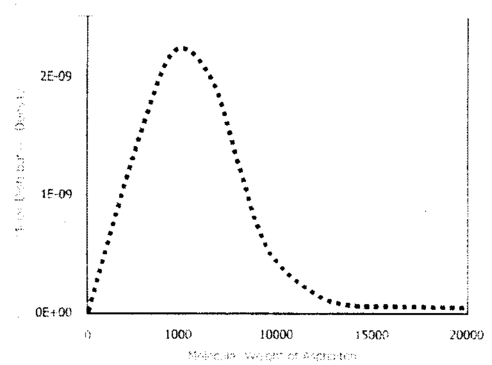
Molecular size distribution of asphaltene of a California crude in solution and after precipitation by the addition of n-C5

Petro-Chem Development Co., Inc.

21

Film Cracking

- Asphaltenes



Molecular weight distribution of asphaltene in the live crude oil A.

Petro-Chem Development Co., Inc.

22

Film Cracking

- Pressure
- Bulk fluid and film temperature
- Cracked heavy gas oil (CHGO) recycle rates and composition
- Inside heat transfer rate
- Peak radiant flux rate

Petro-Chem Development Co., Inc.

23

Asphaltene Destabilization and Dry Sludge Formation

- Higher Asphaltene concentration increases fouling rates
- Higher pressures in the coil increase fouling rates
- Higher bulk and film temperatures increase fouling rates
- Lower CHGO recycle rates increase fouling rates
- CHGO composition can increase fouling rates

Petro-Chem Development Co., Inc.

24

Asphaltene Destabilization and Dry Sludge Formation

- Low inside heat transfer rates can increase fouling rates (low mass velocities in heater coil)
- Higher peak radiant flux rates increase fouling rates
- More velocity steam does not help and can actually increase fouling rates
- Anti-foulants – do not reduce the fouling rates in delayed coker heaters

Petro-Chem Development Co., Inc.

25

Asphaltene Destabilization and Dry Sludge Formation

Fouling rates are increased when the previous adverse conditions cause an overheating of the fluid film and form a dry sludge on the heater tube wall which is not mixed back into the bulk fluid.

Petro-Chem Development Co., Inc.

26

Petro-Chem Case Study

CASE STUDY #1 (Heater NOT designed by Petro-Chem)

HEATER DESCRIPTION:

2 pass, double fired, delayed coker heater
Charge rate = 9500 B/D
Duty = 53 MM Btu/hr

Inlet temperature = 425 Deg. F.
Inlet pressure = 281 psig

Outlet temperature = 935 Deg. F.
Outlet pressure = 125 psig

Pressure drop clean = 156 psi

Velocity steam injection rate = 594 lb/hr per pass

Convection section: 12 bare tubes and 32 fin tubes
    Tube material = A-335-P9
Tube O.D. = 3.5"
    Tube thickness = 0.30" average wall
    Tube I.D. = 2.9"
Radiant section: 44 radiant tubes (28 - 3.5" O.D. and 16 - 4.0" O.D.)
    Tube material = A-335-P9
    Tube O.D. = 3.5" and 4.0"
    Tube thickness = 0.30" and 0.318" average wall
    Tube I.D. = 2.9" and 3.364"
    Note: last 8 tubes per pass were 4.0" O.D.

Average radiant flux rate = 14,850 Btu/Hr-Ft2
Peak radiant flux rate = 17.820 Btu/Hr-Ft2

Petro-Chem Development Co., Inc.

27

Petro-Chem Case Study Continued

HEATER PERFORMANCE:

The heater was reaching 1200 Deg. F. tube metal temperatures (design basis for decoking) 4-5 weeks after decoking. The 28 to 35 day run length was limiting refinery capacity. The old single fired coker heater replaced by this new double fired coker heater had run lengths of 4 months between decoking.

PETRO-CHEM STUDY:

Petro-Chem was commissioned to study the causes of the elevated rates of coking and to recommend solutions which would extend the run lengths to 12 months with the same feed composition. It was not possible to on line spall to the coke drum because of the 2 pass heater configuration. Therefore, long run lengths between pigging or steam/air decoking were a design requirement. In fact, long run lengths were the driving consideration to replace the old single fired heater with the new double fired heater.

1) Bulk Cracking Analysis:

Petro-Chem first looked for long residence times of the bulk fluid temperature above 800 Deg. F. However, the 28 to 35 day run length meant that the temperature rise per day was equal to 5.1 to 6.4 Deg. F. per day. Anything above 3 degrees per day is definitely film cracking. The residence time above 800 Deg. F. was 22.9 seconds which is excellent for a double fired coker heater. This confirmed that bulk cracking was not the coking mechanism and that film cracking was the problem.

2) Petro-Chem analyzed the heater performance using our proprietary film cracking computer modeling. This model takes into account bulk fluid temperature, film temperature, pressure, CHGO composition and flow rate, asphaltene content of the fresh feed, and peak radiant flux rates. The computer model duplicated the short run lengths observed in the field.

Using this model as a building block, Petro-Chem analyzed the various alternatives for decreasing the temperature rise per day to 0.5 Deg. F/day and a run length between decoking of greater than 12 months.

Before implementing the changes, we asked operations to increase excess air levels and load shift duty from the radiant section to the convection section. Load shifting was successful in reducing the rate of fouling. A decrease of only 800 Btu/Hr-Ft2 resulted in a measurable decrease in the tube metal temperature rise per day.

Petro-Chem Development Co., Inc.

28

Petro-Chem Case Study Continued

RECOMMENDATIONS FOR ACHIEVING A ONE YEAR RUN LENGTH:

1) Remove the 4.0" O.D. tubes and replace with 3.5" O.D. tubes
2) Install new transfer line to reduce outlet pressure to 65 psig
3) Control and maintain proper CHGO recycle rate and composition
4) Change burners to variable flux burners
5) Install new V.C. (all liquid) preheater ahead of the combination tower to control tower bottoms temperature and keep charge heater firing rates constant during drum switches and fresh feed composition changes. This also reduced the heat load on the charge heater by 25%.
6) Reduce velocity steam rate

RESULTS:

Over a 14 month period the above recommended changes were implemented. The double fired delayed coker heater now operates with run lengths in excess of 12 months.

It should also be noted that much valuable information and data was gathered after each change. Since changes were made one at a time, we were able to document the improvement in performance associated with each individual change. Our film cracking model has continued to be improved with each case study because the knowledge learned is always included in our data base and computer model algorithms.

Petro-Chem Development Co., Inc.

29

Petro-Chem Film Cooling Technologies ™

- Providing new "knobs" for operators to turn to:

    1. Control the film

    2. Control the flux

Petro-Chem Development Co., Inc.

30

Petro-Chem Film Cooling Technologies ™

Producing **RESULTS**:

- Increase capacity
- Increase run lengths
- Reduction in fouling rates
- Reduction in tube metal temperatures
- Increased tube life

Petro-Chem Development Co., Inc.

31

Petro-Chem Film Cooling Technologies ™

- Recent patents

1. Upflow Double Fired	Control the **film** and **flux**
2. Double Row, Double Fired	Control the **flux**
3. Feed Preheater and Controls	Control the **flux**
4. Circumferential Injection through Special Return Bends of CLGO/CHGO or Any Other Beneficial Fluid into the Fluid Film	Control the **film**
5. Adjustable Louvers	Control the **flux**
6. Insitu Flux Probe	Control the **flux**

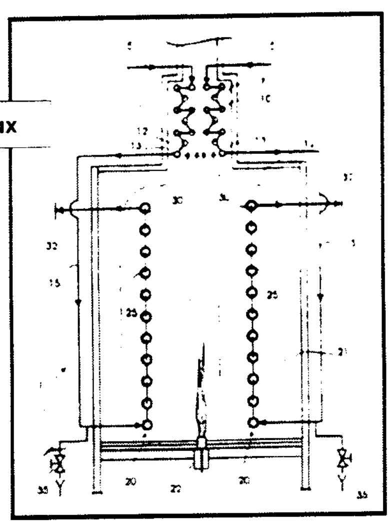
Petro-Chem Development Co., Inc.

32

Petro-Chem Recent Patents

Upflow Double Fired

Control the **film** and **flux**

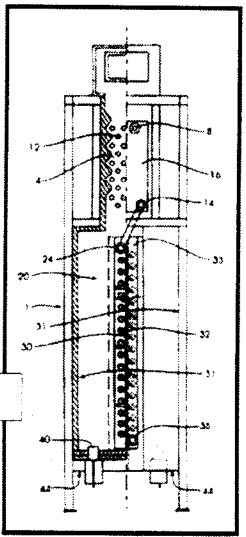


Petro-Chem Development Co., Inc.

33

Petro-Chem Recent Patents

Double Row, Double Fired



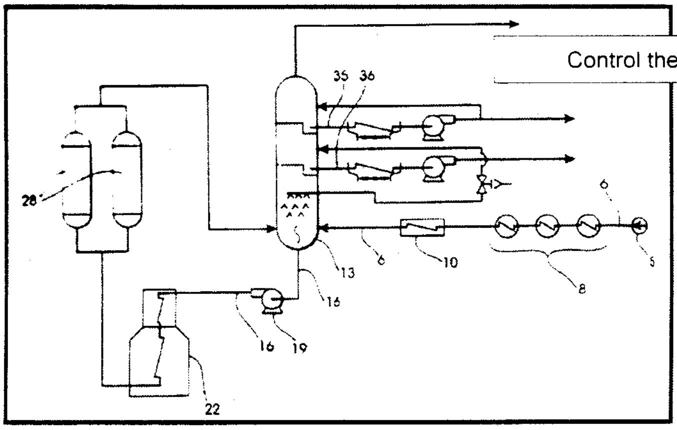
Control the **flux**

Petro-Chem Development Co., Inc.

34

Petro-Chem Recent Patents

Feed Preheater and Controls



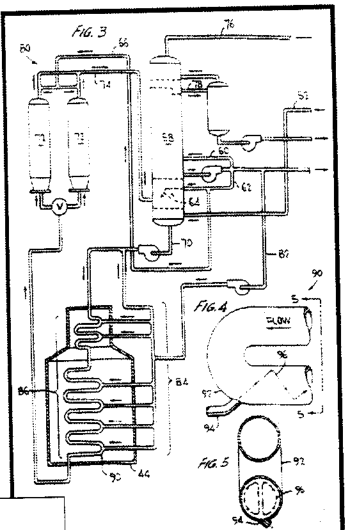
Control the **flux**

Petro-Chem Development Co., Inc.

35

Petro-Chem Recent Patents

Circumferential Injection through Special Return Bends of CLGO/CHGO or Any Other Beneficial Fluid into the Fluid Film



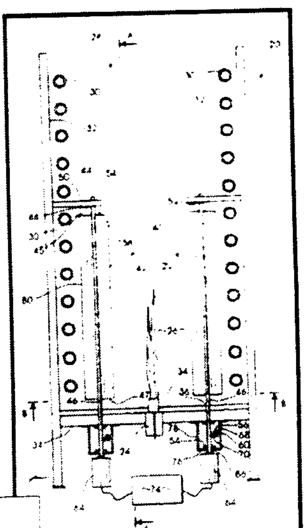
Control the **film**

Petro-Chem Development Co., Inc.

36

Petro-Chem Recent Patents

Adjustable Louvers

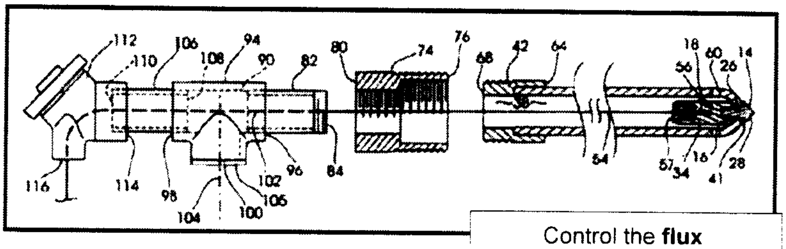


Control the **flux**

Petro-Chem Development Co., Inc.

Petro-Chem Recent Patents

Insitu Flux Probe



Control the **flux**