# CBE 30399

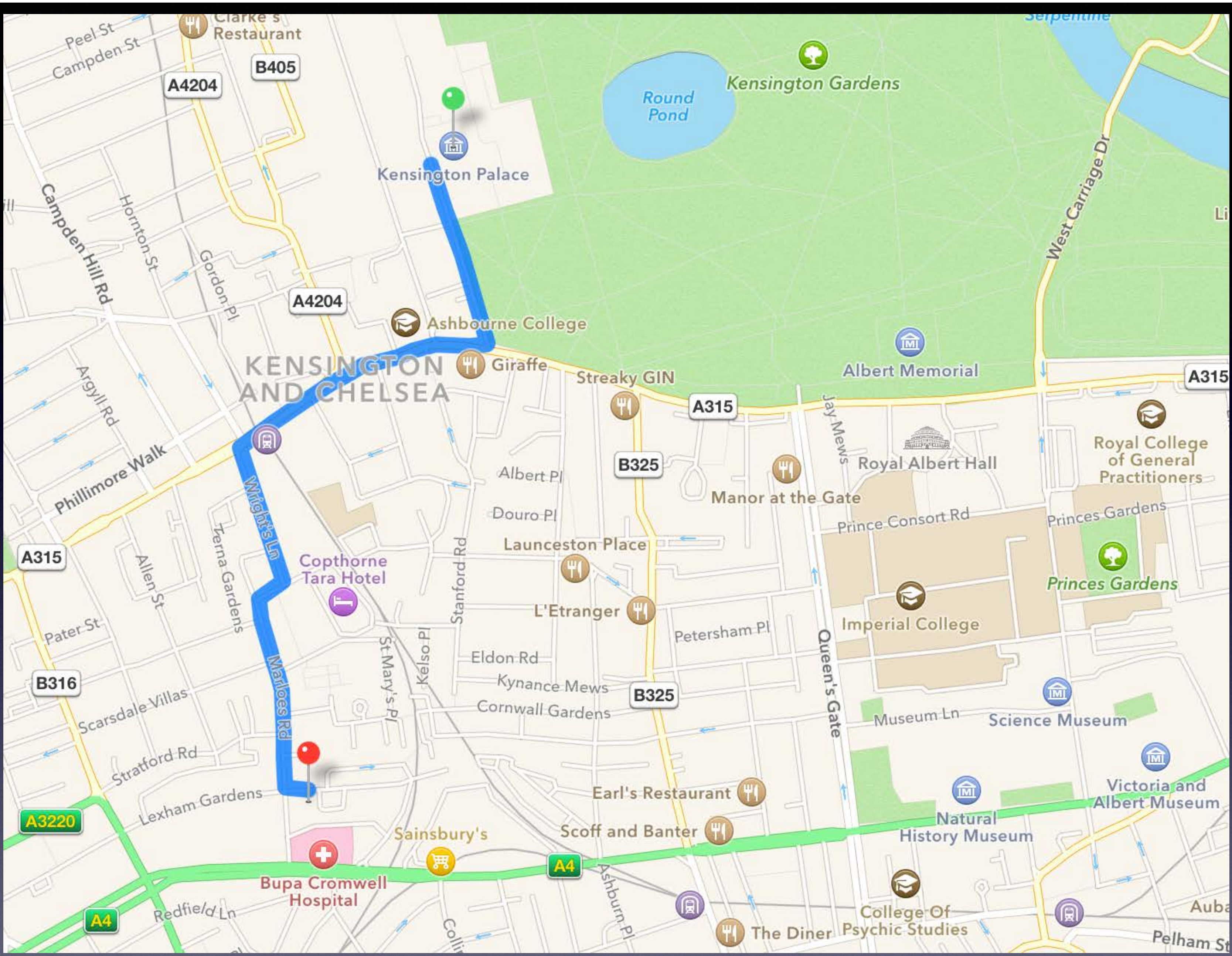
February 25, 2016

# Could read some history before you go… and then explore

- The Monarchy is a special institution to the people of Great Britain
    - or at least England….
- Kensington Palace is in your neighborhood
    - Childhood home of Queen Victoria
    - Plenty of “videos” and “movies” to get info about her

# Kensington Palace

- Queen Victoria’s childhood home



Clarke's Restaurant
Peel St
Campden St
B405
A4204
Kensington Palace
Round Pond
Kensington Gardens
West Carriage Dr
Campden Hill Rd
Hornton St
Gordon Pl
A4204
Ashbourne College
KENSINGTON AND CHELSEA
Giraffe
Streaky GIN
A315
Albert Memorial
A315
Argyll Rd
Phillimore Walk
Wright's Ln
Albert Pl
B325
Royal Albert Hall
Manor at the Gate
Royal College of General Practitioners
Douro Pl
Prince Consort Rd
Princes Gardens
A315
Allen St
Terna Gardens
Copthorne Tara Hotel
Launceston Place
Stanford Rd
Princes Gardens
L'Etranger
Petersham Pl
Imperial College
Queen's Gate
Pater St
Marloes Rd
St Mary's Pl
Kelso Pl
Eldon Rd
Kynance Mews
B325
B316
Scarsdale Villas
Cornwall Gardens
Museum Ln
Science Museum
Jay Mews
Stratford Rd
Earl's Restaurant
Victoria and Albert Museum
Natural History Museum
A3220
Lexham Gardens
Sainsbury's
Scoff and Banter
A4
Bupa Cromwell Hospital
Ashburn Pl
A4
Redfield Ln
The Diner
College Of Psychic Studies
Pelham St

# Imperial Flowsheet

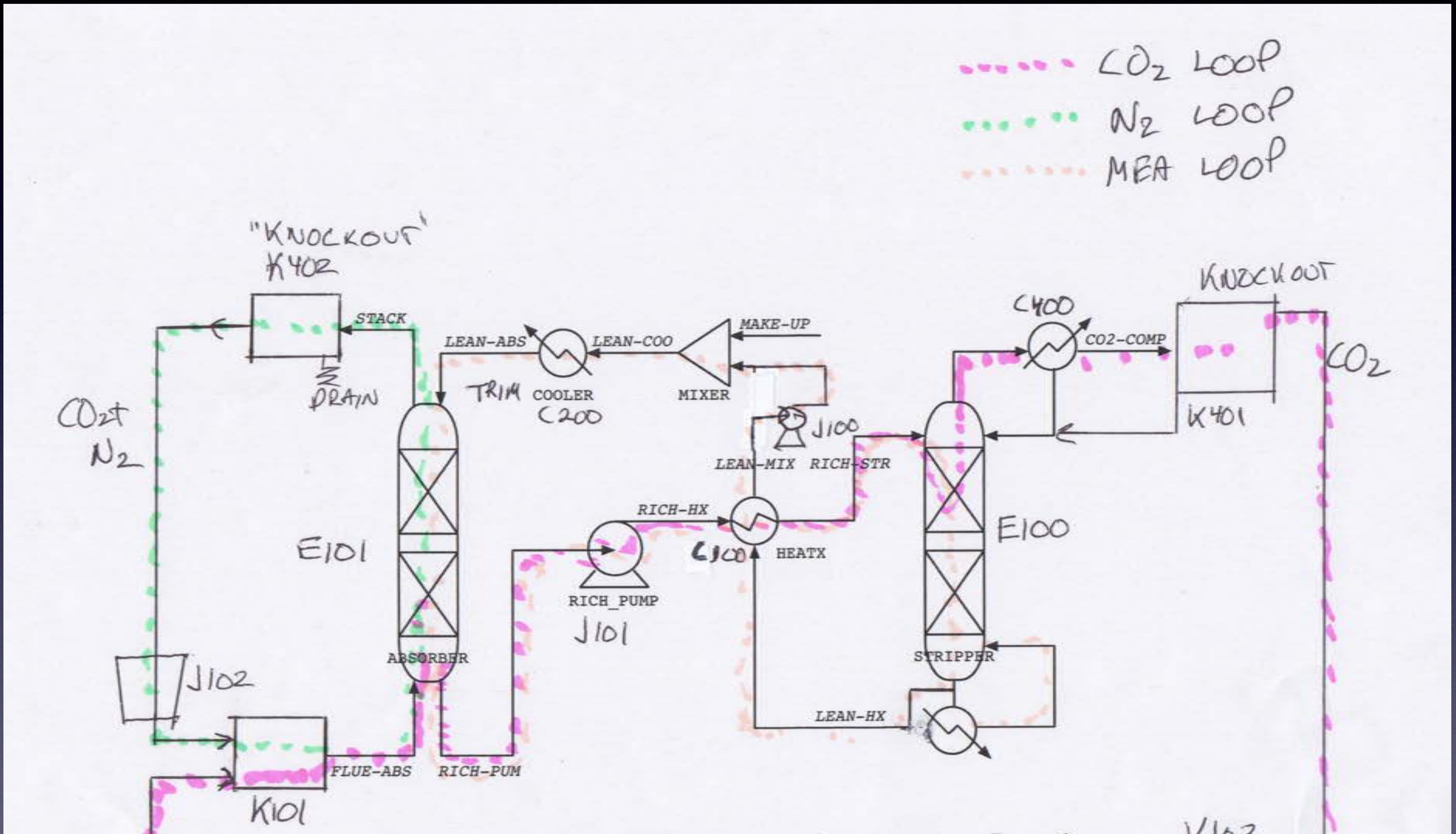
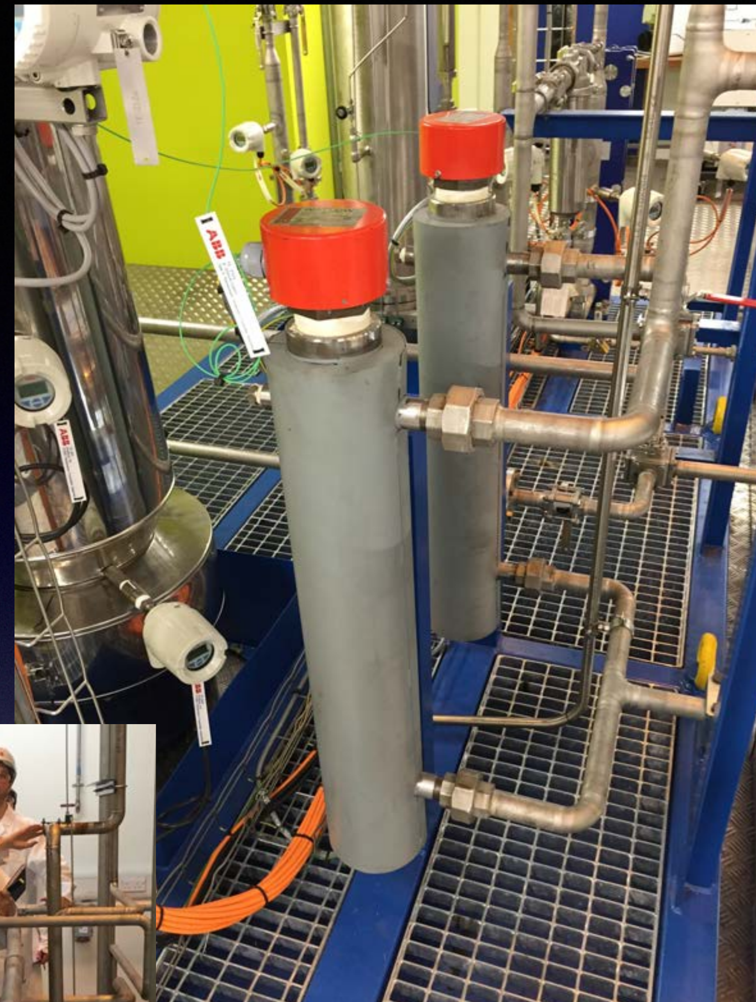


Figure 4.1: Base MEA absorption process flowsheet

# Pipes!

# Pipes

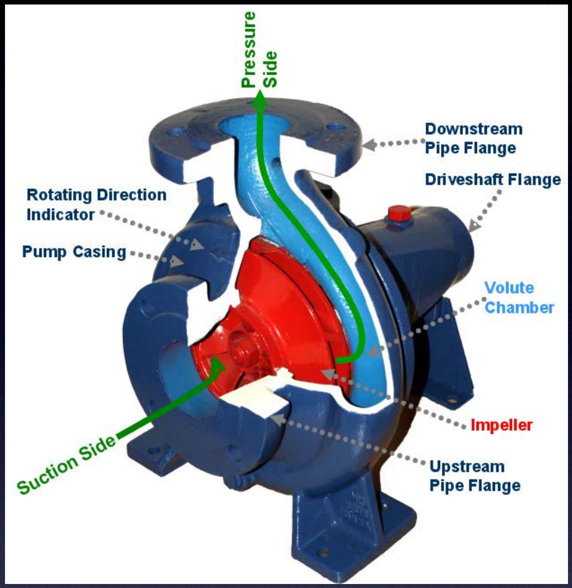


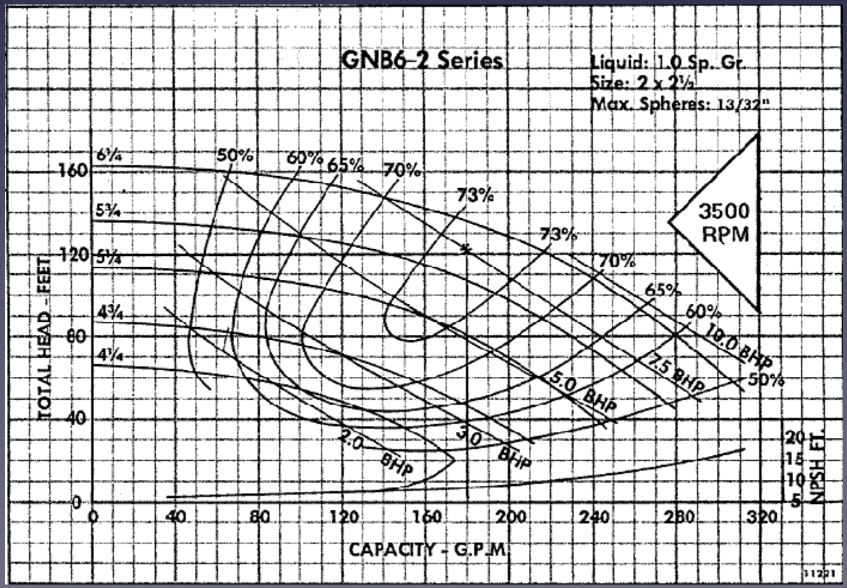
# Pumping fluids

- Blowers and compressors are used for gases
- For low and moderate viscosity liquids, low to very high volumetric flow rates…
  - Centrifugal pumps are most common.
    - *Imperial* is a special case… they use mostly positive displacement pumps with direct motor drive.
- The other key word is “positive displacement”
  - This means that specific volumes of fluid are forced through the pump/compressor/blower (with no back flow) so that the flow rate must be controlled by the speed of the motor/driving coupling.

# Centrifugal pump

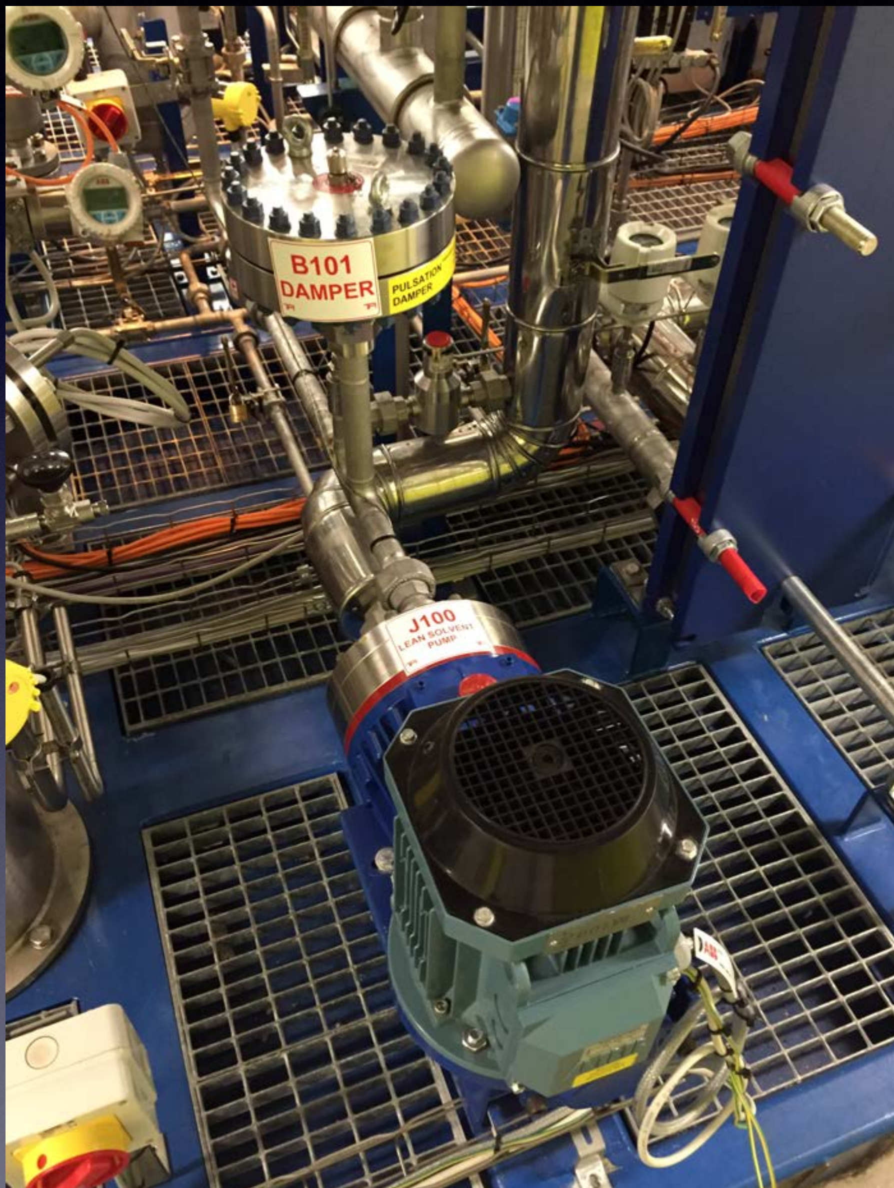
- Not positive displacement.  A valve at the outlet can control the flowrate.
  - These can be throttled down quite a bit without causing any damage.

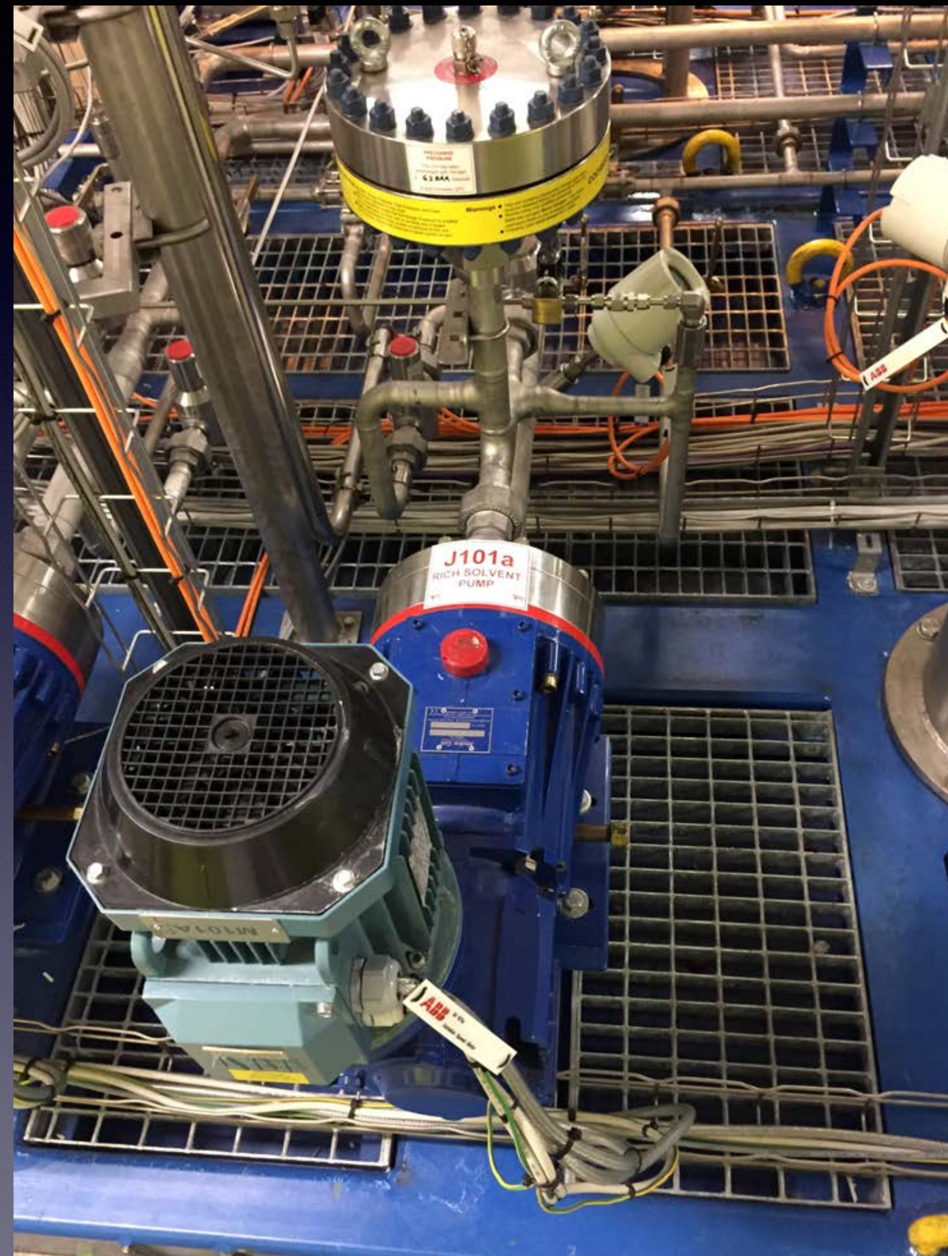



Pump Curves

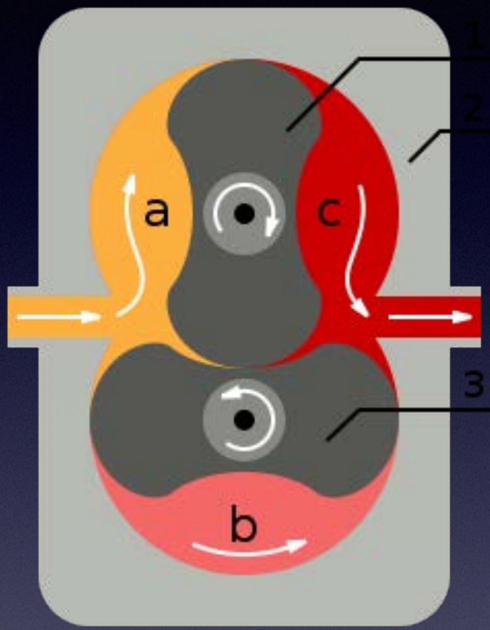
# Direct Drive positive displacement pumps

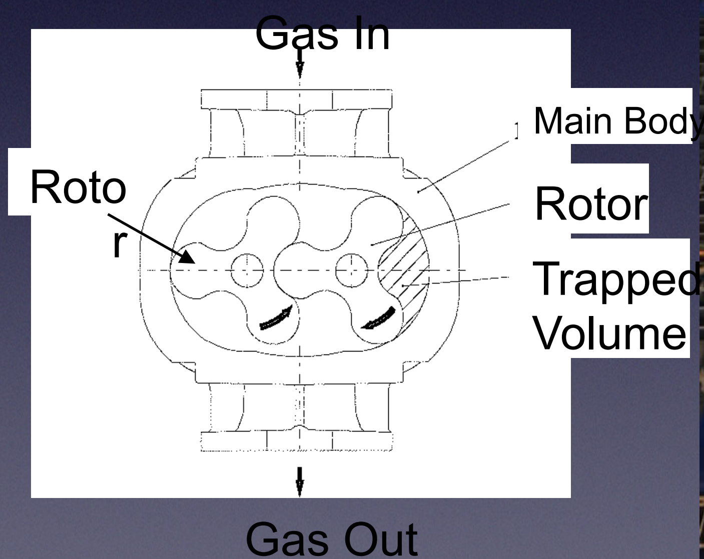


# “Blower”

- Gases are pumped using blowers and compressors
- Imperial has a “lobe” blower for the N2 recycle.
- Blowers usually provide some modest increase in pressure, but handle large volumes of air efficiently

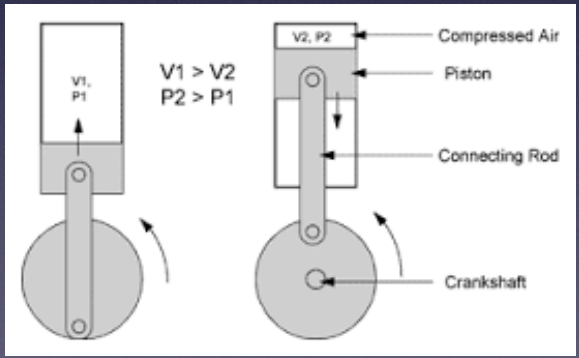



Gas In
Main Body
Roto
r
Rotor
Trapped
Volume
Gas Out


K102
KNOCK OUT
POT
J102
GAS BLOWER
M102
ABB

# Compressor

- Compressors usually provide some "ratio" increase in pressure.
- Hence the power requirements are significant
- Come in all sizes
- Reciprocating compressors are generally used for smaller scale flows (<50 HP)
- Imperial Compressor is a single-stage ("piston") reciprocating compressor


Pistons on top

# Pipes

- Standard sizes of fabrication
    - "schedule"… relates to wall thickness
- Chose material for appropriate compatibility
    - 304 Stainless is fine for MEA

## NPS tables for selected sizes [edit]

### NPS ⅛ to NPS 3½ [edit]

| NPS[6] | DN [2] | OD [in (mm)] | Wall thickness [in (mm)] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | SCH 5s | SCH 10s/20 | SCH 30 | SCH 40s/40 /STD | SCH 80s/80 /XS | SCH 120 | SCH 160 | XXS |
| ⅛ | 6 | 0.404 (10.26) | 0.035 (0.889) | 0.049 (1.245) | 0.057 (1.448) | 0.068 (1.727) | 0.095 (2.413) | — | — | — |
| ¼ | 8 | 0.540 (13.72) | 0.049 (1.245) | 0.065 (1.651) | 0.073 (1.854) | 0.088 (2.235) | 0.119 (3.023) | — | — | — |
| ⅜ | 10 | 0.675 (17.15) | 0.049 (1.245) | 0.065 (1.651) | 0.073 (1.854) | 0.091 (2.311) | 0.126 (3.200) | — | | — |
| ½ | 15 | 0.840 (21.34) | 0.065 (1.651) | 0.083 (2.108) | 0.095 (2.413) | 0.109 (2.769) | 0.147 (3.734) | — | 0.188 (4.775) | 0.294 (7.468) |
| ¾ | 20 | 1.050 (26.67) | 0.065 (1.651) | 0.083 (2.108) | 0.095 (2.413) | 0.113 (2.870) | 0.154 (3.912) | — | 0.219 (5.563) | 0.308 (7.823) |
| 1 | 25 | 1.315 (33.40) | 0.065 (1.651) | 0.109 (2.769) | 0.114 (2.896) | 0.133 (3.378) | 0.179 (4.547) | — | 0.250 (6.350) | 0.358 (9.093) |
| 1¼ | 32 | 1.660 (42.16) | 0.065 (1.651) | 0.109 (2.769) | 0.117 (2.972) | 0.140 (3.556) | 0.191 (4.851) | — | 0.250 (6.350) | 0.382 (9.703) |
| 1½ | 40 | 1.900 (48.26) | 0.065 (1.651) | 0.109 (2.769) | 0.125 (3.175) | 0.145 (3.683) | 0.200 (5.080) | — | 0.281 (7.137) | 0.400 (10.160) |
| 2 | 50 | 2.375 (60.33) | 0.065 (1.651) | 0.109 (2.769) | 0.125 (3.175) | 0.154 (3.912) | 0.218 (5.537) | 0.250 (6.350) | 0.343 (8.712) | 0.436 (11.074) |
| 2½ | 65 | 2.875 (73.03) | 0.083 (2.108) | 0.120 (3.048) | 0.188 (4.775) | 0.203 (5.156) | 0.276 (7.010) | 0.300 (7.620) | 0.375 (9.525) | 0.552 (14.021) |
| 3 | 80 | 3.500 (88.90) | 0.083 (2.108) | 0.120 (3.048) | 0.188 (4.775) | 0.216 (5.486) | 0.300 (7.620) | 0.350 (8.890) | 0.438 (11.125) | 0.600 (15.240) |
| 3½ | 90 | 4.000 (101.60) | 0.083 (2.108) | 0.120 (3.048) | 0.188 (4.775) | 0.226 (5.740) | 0.381 (9.677) | — | — | 0.636 (16.154) |

Tolerance: The tolerance on pipe OD is +1/64 (.0156)inch, -1/32 (.0312)inch.[7]

## Stainless Steel Chemical Resistance Chart

### Chemicals M-O

| Chemical | Stainless Steel 304 Compatibility | Stainless Steel 316 Compatibility |
|---|---|---|
| Magnesium Bisulfate | A-Excellent | A-Excellent |
| Magnesium Carbonate | B-Good | B-Good |
| Magnesium Chloride | D-Severe Effect | D-Severe Effect |
| Magnesium Hydroxide | B-Good | A-Excellent |
| Monochloroacetic acid | A-Excellent | A-Excellent |
| Monoethanolamine | A-Excellent | A-Excellent |
| Morpholine | N/A | A-Excellent |

# Chemical Compatibility

## Chemical Compatibility Results

Material and their Compatibility Rating with your selected Chemical are listed below:

New search

**Chemical Selected**:
Ethanolamine

Shop now

| Material | Compatibility |
|---|---|
| ABS plastic | N/A |
| Acetal (Delrin®) | D-Severe Effect |
| Aluminum | B-Good |
| Brass | N/A |
| Bronze | B-Good |
| Buna N (Nitrile) | B-Good |
| Carbon graphite | A-Excellent |
| Carbon Steel | B-Good |
| Carpenter 20 | A-Excellent |
| Cast iron | N/A |
| Ceramic Al203 | A-Excellent |
| Ceramic magnet | N/A |
| ChemRaz (FFKM) | A-Excellent |
| Copper | D-Severe Effect |
| CPVC | N/A |
| EPDM | B-Good |
| Epoxy | A[1]-Excellent |
| Fluorocarbon (FKM) | D-Severe Effect |
| Hastelloy-C® | B-Good |

**Explanation of Footnotes**
1. Satisfactory to 72°F (22°C)
2. Satisfactory to 120°F (48°C)

**Ratings -- Chemical Effect**

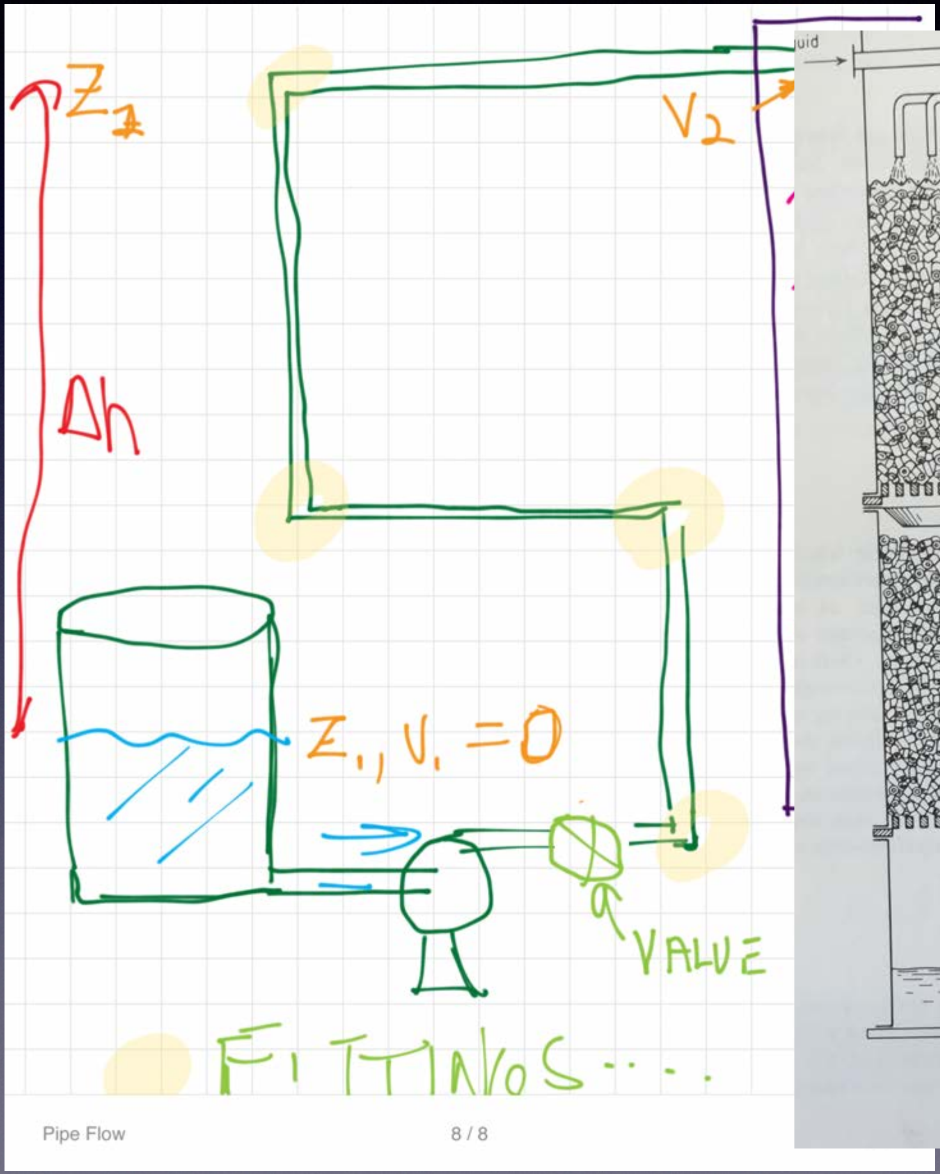
**A = Excellent.**
**B = Good --** Minor Effect, slight corrosion or discoloration.
**C = Fair --** Moderate Effect, not recommended for continuous use. Softening, loss of strength, swelling may occur.
**D = Severe Effect,** not recommended for ANY use.
**N/A =** Information not available.

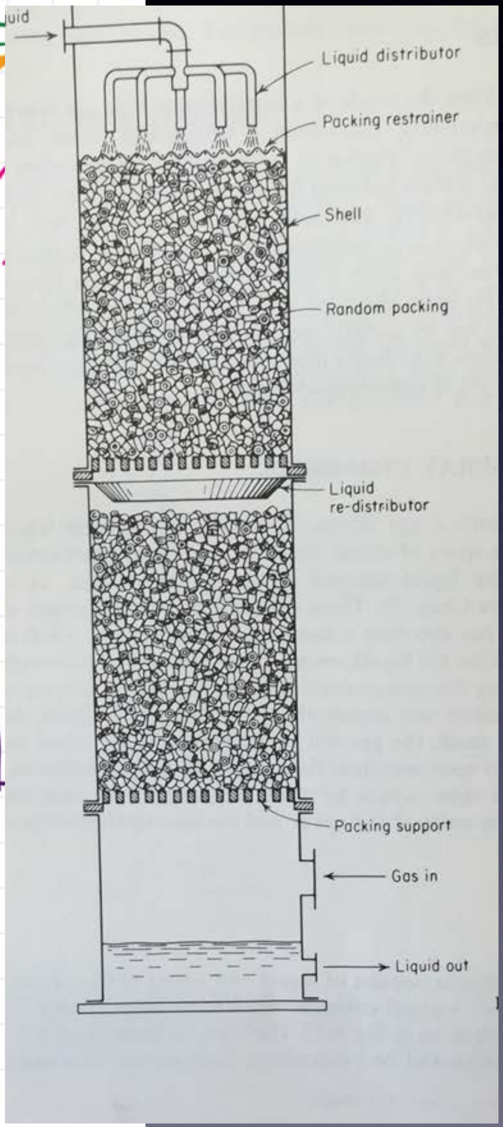
# Pipe fittings

# Welded joints/Bolted Flanges


# Pipe threads

# How big should the pump be?



# Engineering Tradeoff

- Capital costs
- Operating Costs
- “Optimal pipe diameter” is a classic problem
  - For engineers and
  - It is evident in your circulatory system!

# “Regimes of Pipe Flow”

- “Laminar”
  - Straight streamlines
- “Turbulent”
  - Irregularity of the flow causes increased pressure drop
- “You” don’t get to choose.  The system and conditions determine which will occur!

# Dye Streak Experiment

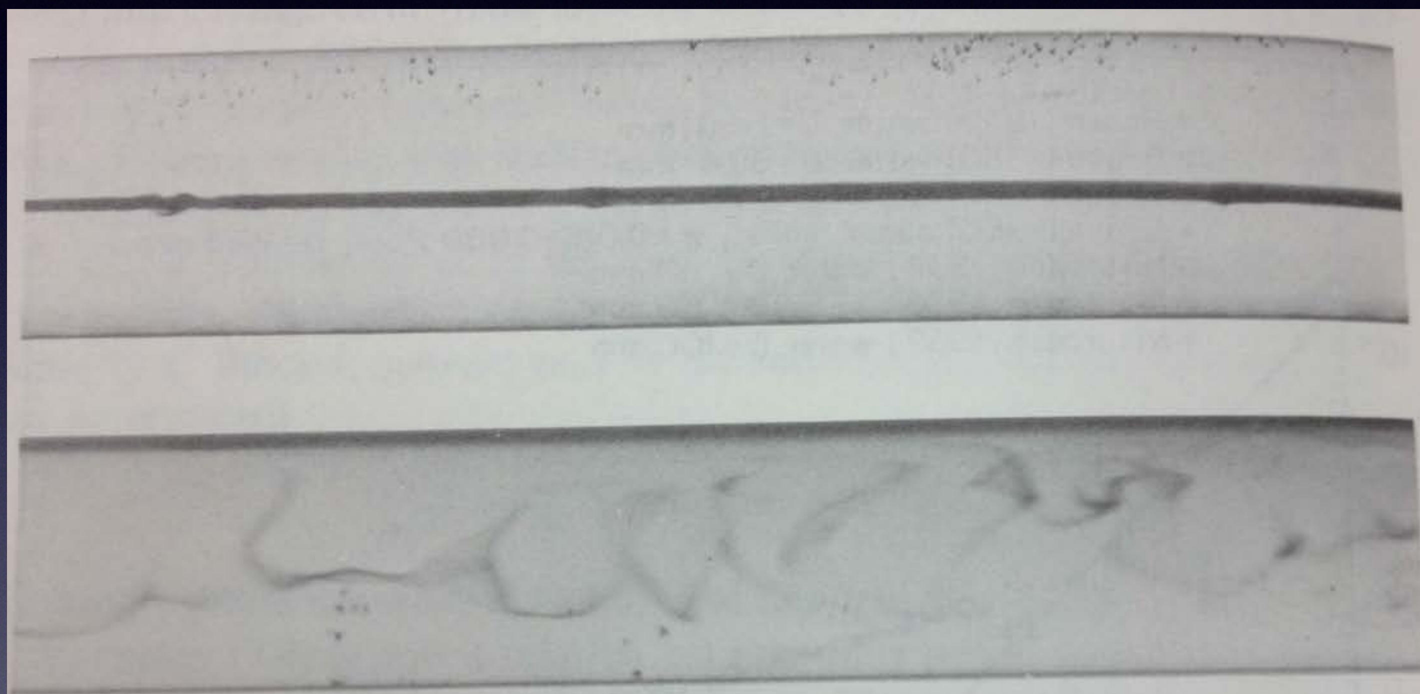
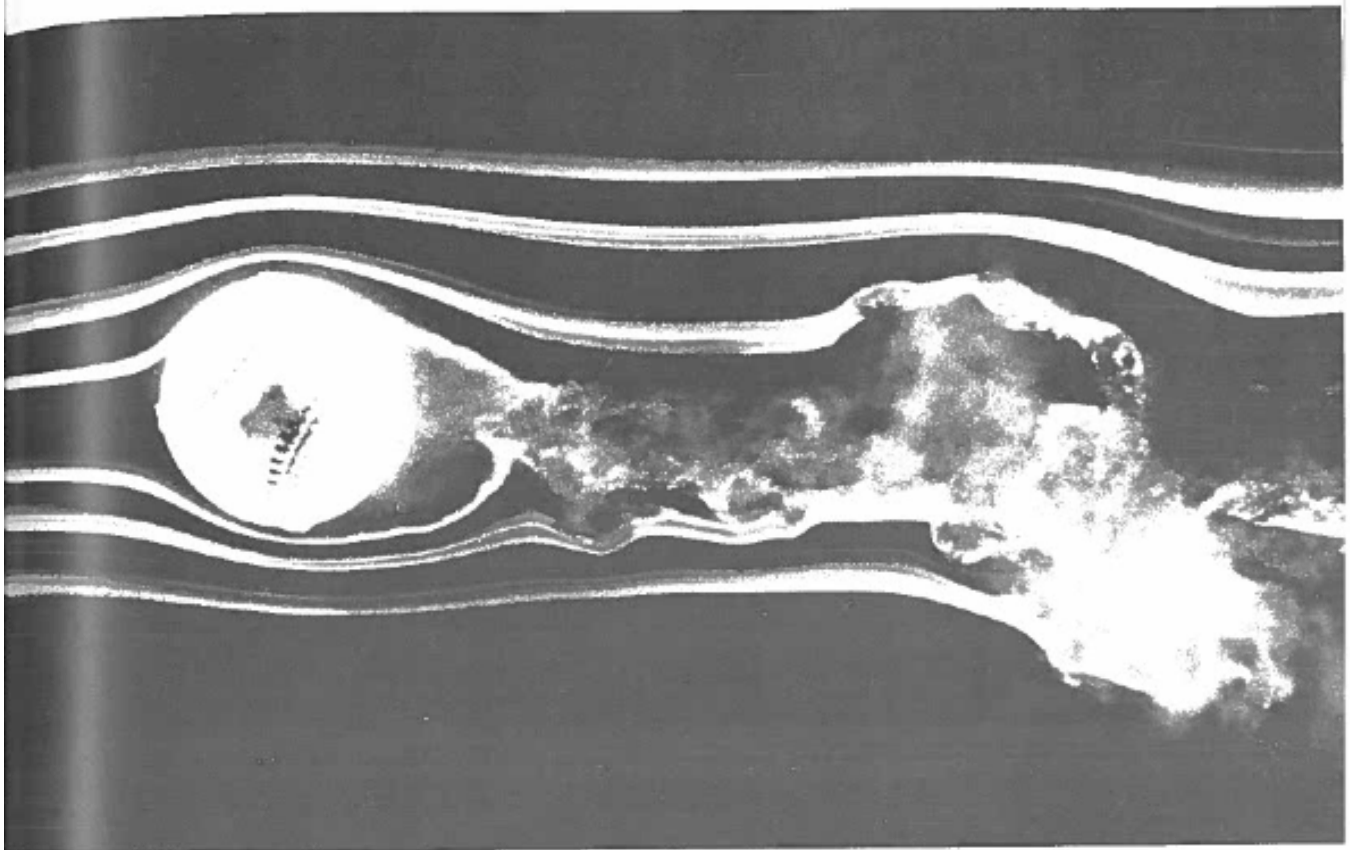


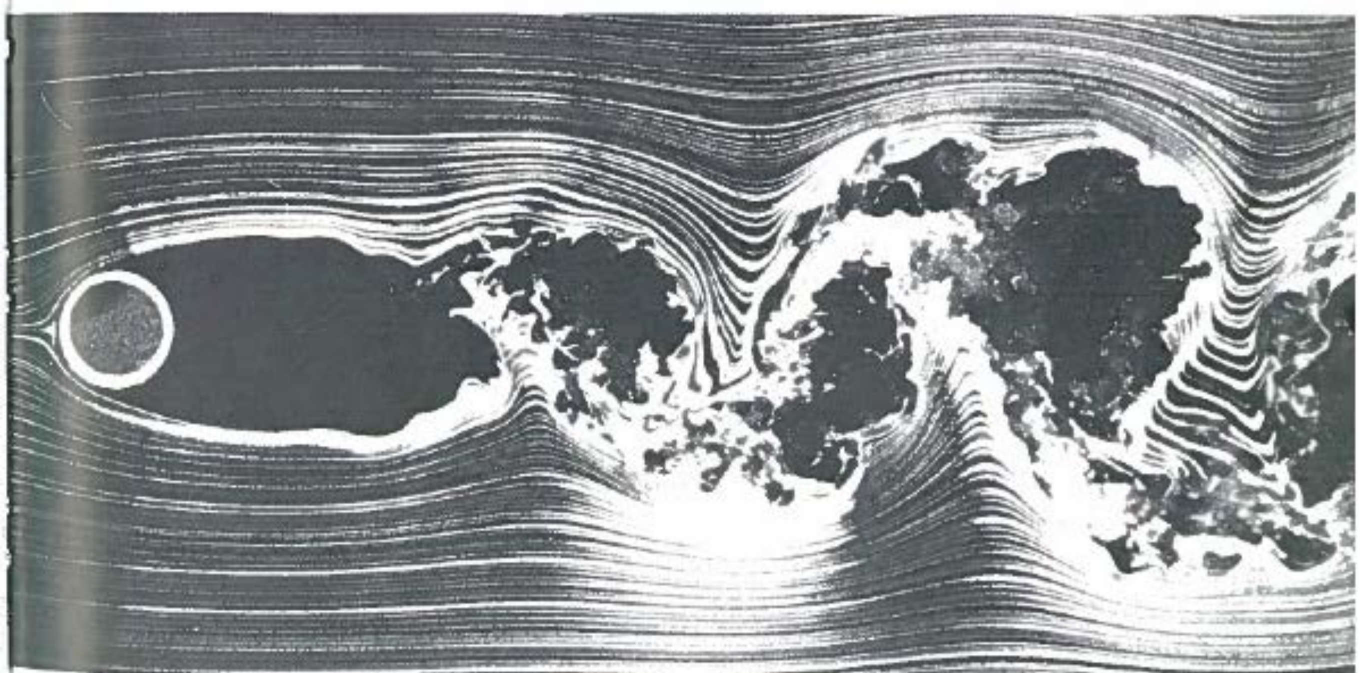
**Figure 3-2.** Re-creation of Reynolds' dye stream experiment. (a) Laminar flow, Re = 1500, dye stream is undisturbed. (b) Turbulent flow, Re = 3000, dye stream is dispersed. Flow is from left to right in both photographs. Photographs by D. Smith, provided courtesy of the Chemical Engineering Department, Monash University.

Photo taken at Notre Dame, presumably in a building that used to be SSW of Jordan Hall.



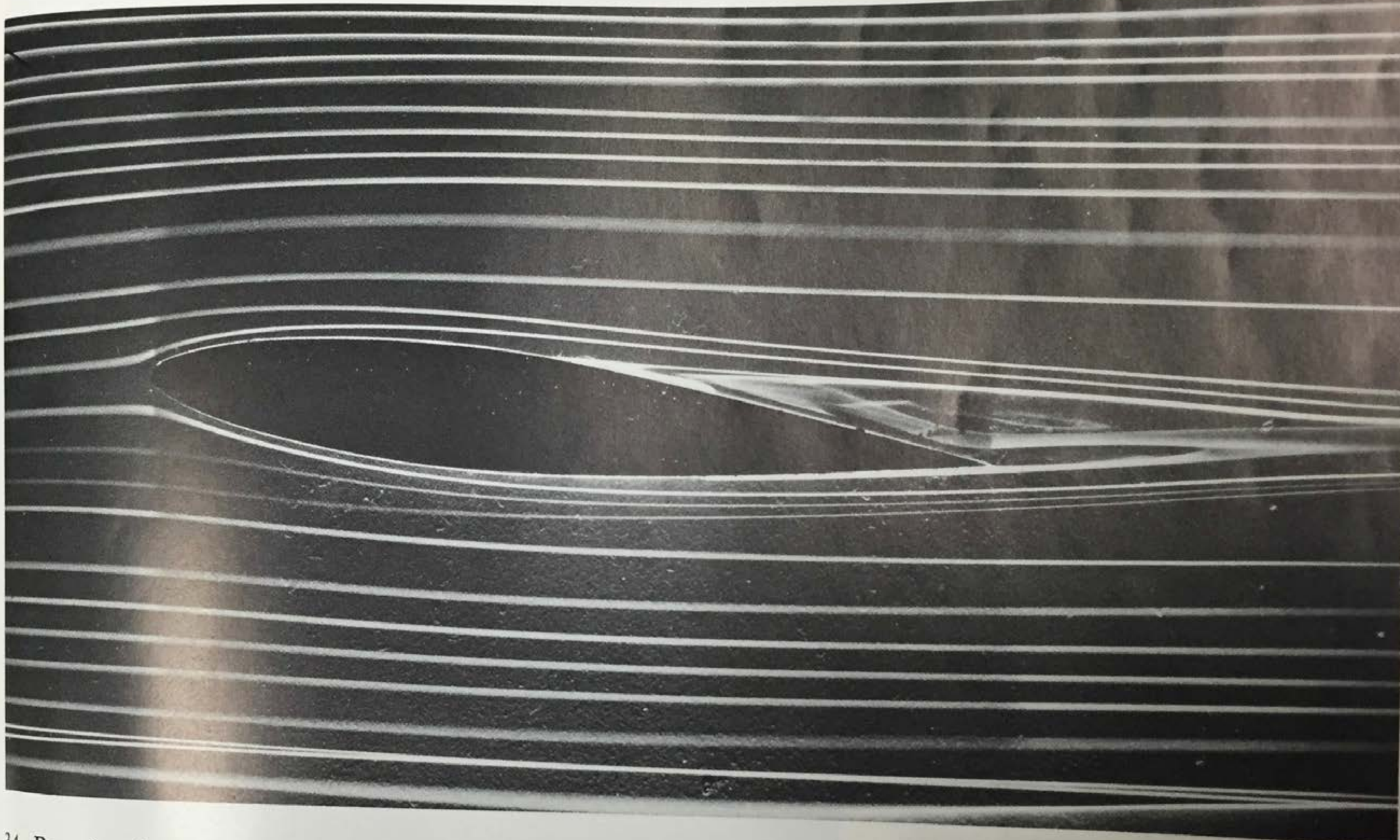
**66. Spinning baseball.** The late F. N. M. Brown devoted many years to developing and using smoke visualization in wind tunnels at the University of Notre Dame. Here the flow speed is about 77 ft/sec and the ball is rotated at 630 rpm. This unpublished photograph is similar to several in Brown 1971. *Photograph courtesy of T. J. Mueller*

# Fast flow past a cylinder



**48. Circular cylinder at $R=10{,}000$.** At five times the speed of the photograph at the top of the page, the flow pattern is scarcely changed. The drag coefficient consequently remains almost constant in the range of Reynolds number spanned by these two photographs. It drops later when, as in figure 57, the boundary layer becomes turbulent at separation. *Photograph by Thomas Corke and Hassan Nagib*

# Boundary-Layer must be very thin and viscous effects confined to region close to surface

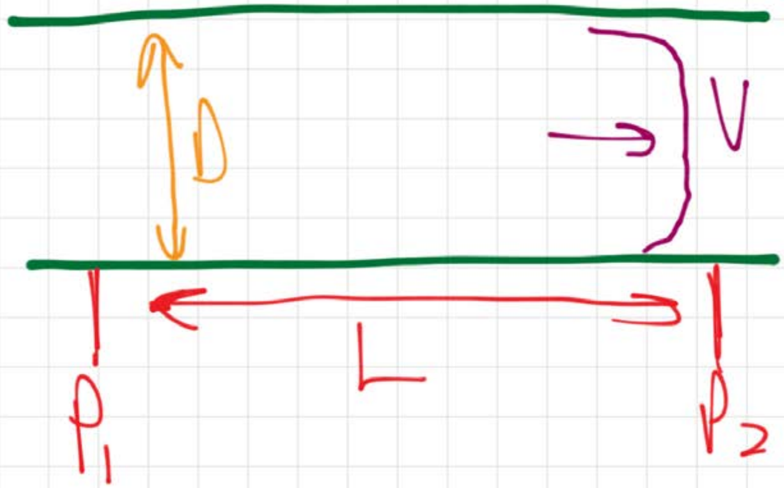


34. **Boundary-layer separation on an inclined airfoil.** When the NACA 64A015 airfoil of figure 23 is raised to 5° incidence the laminar boundary layer separates from the rear half of the upper surface. The flow remains attached to the lower surface, from which it leaves tangentially at the trailing edge. Streamlines are shown by colored fluid filaments in water. *ONERA photograph, Werlé 1974*

# boundary-layer separation and "reattachment"

**35. Leading-edge separation on a plate with laminar reattachment.** A flat plate 2 per cent thick with beveled edges is inclined at 2.5° to the stream. The laminar boundary layer separates at the leading edge over the upper surface. At this Reynolds number of 10,000 based on length it then reattaches while still laminar, enclosing a long leading-edge "bubble" of recirculating fluid. Visualization is by air bubbles in water. *ONERA photograph, Werlé 1974*

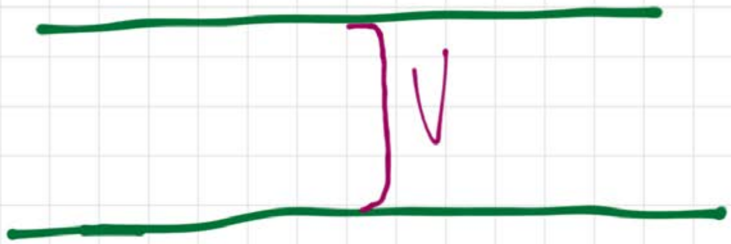
How to characterize pipe flow




μ — VISCOSITY

ρ — DENSITY

Essentially all process flows are turbulent
So that the velocity profile is relatively flat

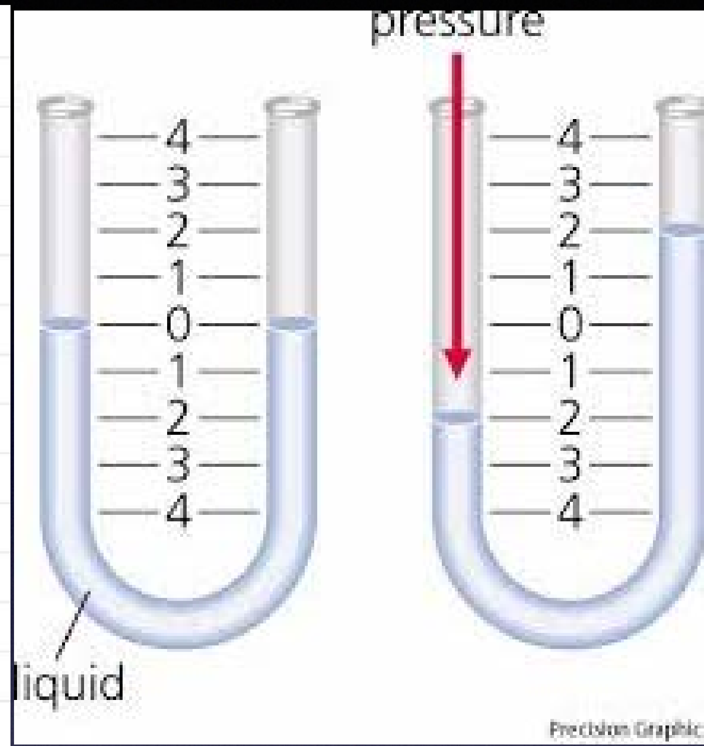



Two dimensionless parameters
Reynolds number
Friction factor

$$Re \equiv \frac{D V \rho}{\mu}$$

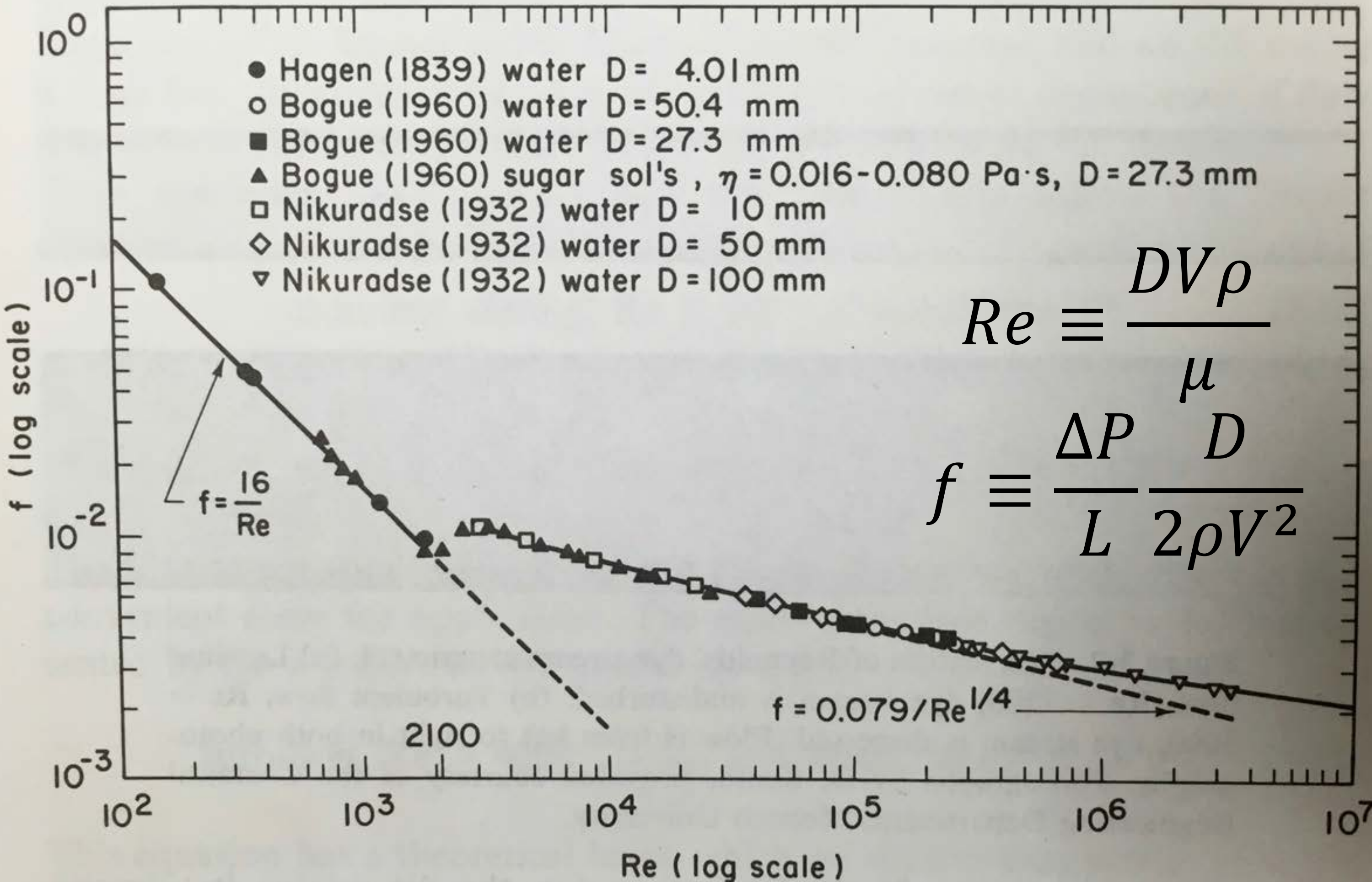
$$f \equiv \frac{\Delta P\, D}{2 L \rho V^2}$$






$$\Delta p = \rho\, g\, \Delta h$$

# Laminar and turbulent pipe flow




$$Re \equiv \frac{DV\rho}{\mu}$$

$$f \equiv \frac{\Delta P}{L}\frac{D}{2\rho V^2}$$

From: M. M. Denn, Process Fluid Mechanics

**Figure 3-1.** Friction factor as a function of Reynolds number for incompressible Newtonian fluids.

FOR $Re \leq 2100$

$$f = \frac{16}{Re} \quad \text{(EXACT RESULT)}$$

LAMINAR FLOW

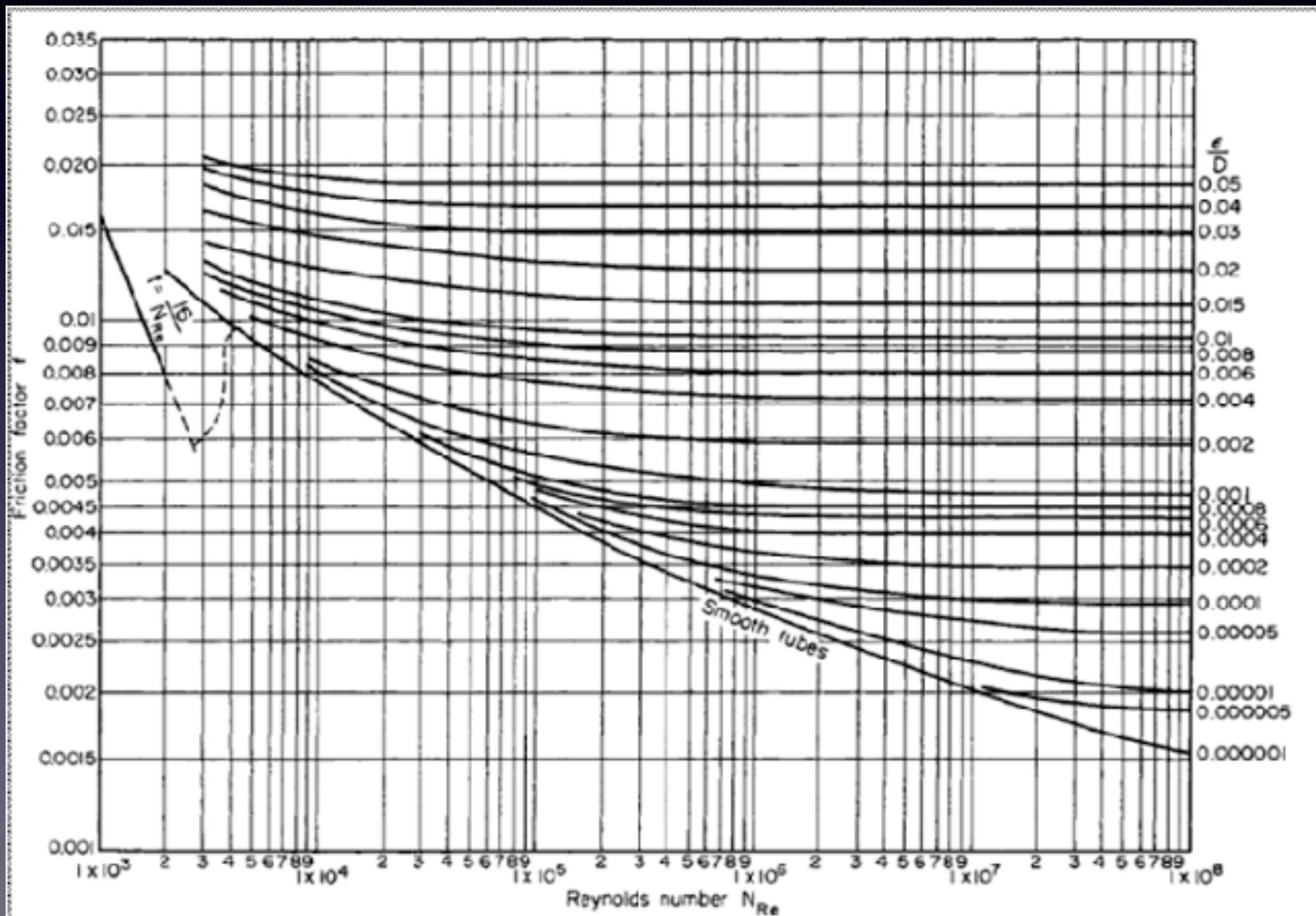
---

FOR $Re \geq 5000$

$$f = 0.079\, Re^{-.25}$$

Typical homework problem would be something like you have 10 GPM of water flowing in a 1-in schedule 40 pipe. What is the Reynolds number? What is the pressure drop? What is the power necessary for pumping this?

# Friction factor — Reynolds number chart



# Imperial Lab


# Schematic

- You calibrate by weighing oil collected in tank.
- Then you collect data from the pressure transducers as a function of flow rates

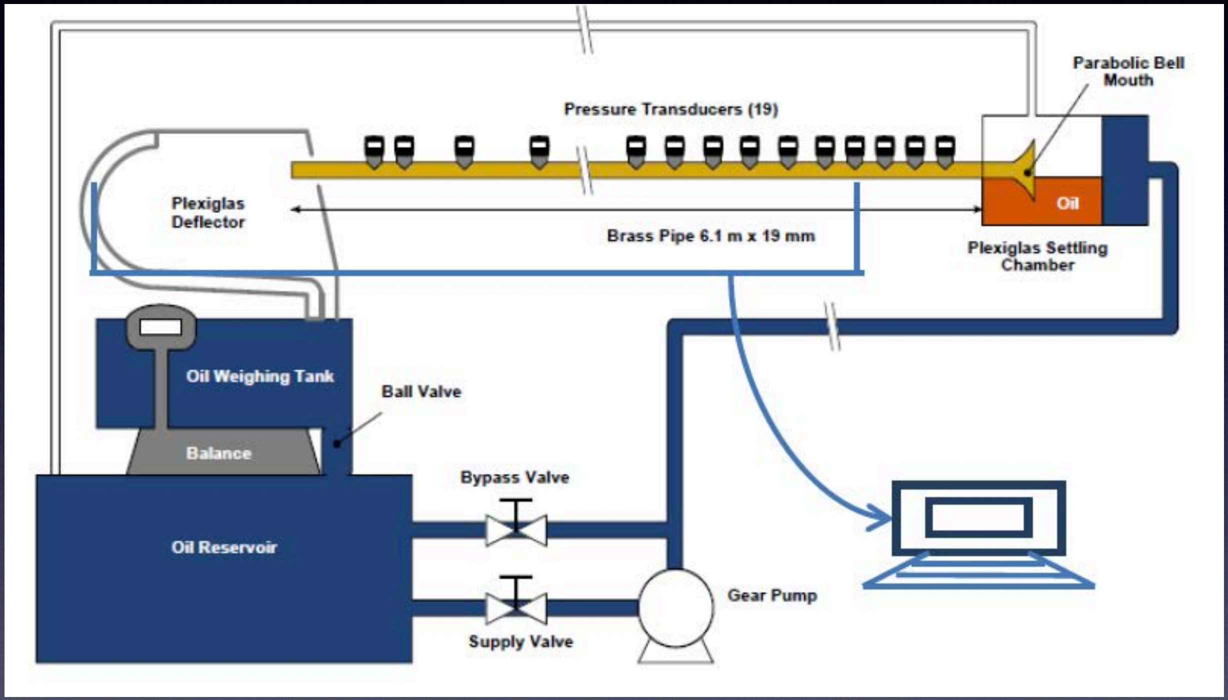



**Figure 3:** Schematic Design of Apparatus used in Pipe Flow Experiment

# Experiment data

- Pressure readings at all of the transducers for all settings of the pump speed (flowrate)
  - You will see that the pressure varies linearly with distance except for the first ~3-4 transducers— this is the pressure drop
- Flow will be in laminar region. You will reproduce the friction-factor Reynolds number plot and see how well it fits

# Friction factor plot

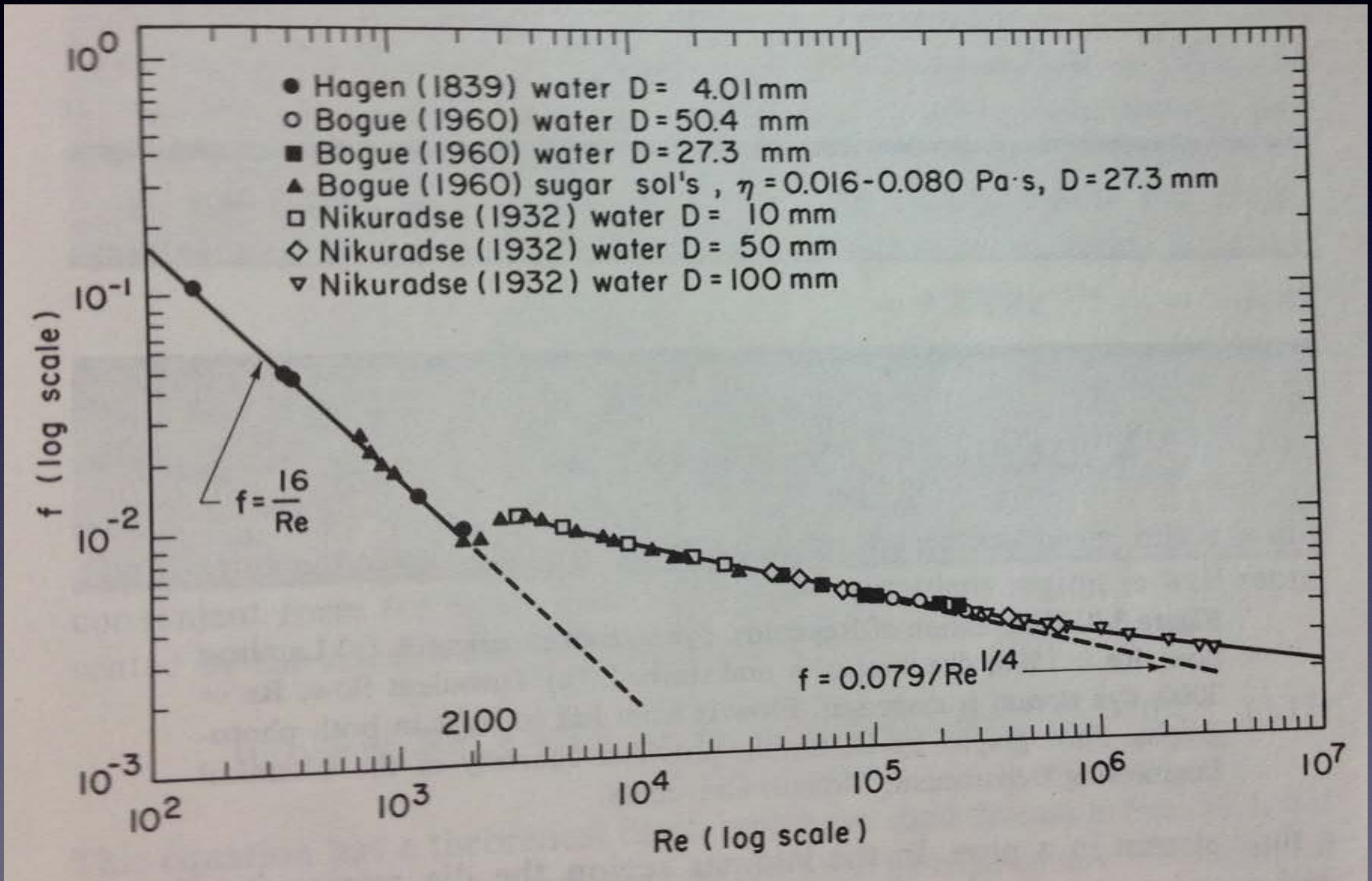



Figure 3.1 Friction factor as a function of Reynolds number for incom-

For a piping system, you would worry about

* height change (takes power to pump up!)
* frictional "losses" that must be overcome
* any acceleration of fluid

BASIC EQUATION

2.7-28 GEANKOPLIS

ENGINEERING BERNOULLI EQUATION:

$\alpha = 1$ TURB' FLOW

$$\frac{1}{2\alpha}\left(v_2^2 - v_1^2\right) + g\left(z_2 - z_1\right) + \frac{P_2 - P_1}{\rho} + \sum F + \overset{0}{\dot{W}_s} = 0$$