総 説
REVIEW

유동층의 공업적 이용

田 海 秀·李 濟 根
高麗大學校 工科大學 化學工學科

Industrial Applications of Fluidized Bed

Hai-Soo Chun and Jea-Keun Lee

Department of Chemical Engineering, College of Engineering
Korea University, Seoul 132, *Korea*

요 약

최근에는 流動層에 대한 應用硏究가 活潑하다. 本報(第二報)에서는 流動層의 應用面에 대한 레뷰와 몇개의 流動層反應器(特殊型)에 대한 特性을 살펴보고자 한다.

Abstract

In recent years some noteworthy developments and the practical applications of fluidized beds to industry have been reported as the significance of fluidized bed has been recognized more and more. In this part Ⅱ, recent advances on applied parts of fluidized beds are reviewed and characteristics of some special types will be discussed.

1. 서 론

1970년 이래 流動層에 대한 模型化가 성행하다가 최근에는 그 應用面에 대한 硏究, 특히 石炭, 重質油, 廢棄物의 燃燒에 의한 에너지化 및 氣體化, 鐵鑛石의 直接還元, 放射性廢棄物의 處理, 廢熱回收등 에너지回收와 環境分野에 대한 硏究가 두드러지게 進行되여 지고있다.

流動層[2], 噴流層[4] 및 傳熱[1]에 관한 單行本이 發刊되였고, 流動層에 대한 國際會議가 Toulouse (1973), Califonia (1975)에서, 反應工學에 대한 國際심포지움이 歐美에서, AIChE의 年會등에서 각각 發刊된 Proceedings[3,7] 또는 Symposium Series[11~17]가 있다. 流動層燃燒에 관한 London[8] 및 Verginia[9] 國際會議(모두 1975년)의 Proceedings, 廢棄物의 에너지로의 變換方法에 대한 Montreaux 國際會議의 Proceedings[19]가 發刊되였다. 그리고 AIChE年會에서도 大氣汚染과 廢

棄物處理의 部會가 있었고, 流動層技術이 많이 포함된 Symposium Series[11~8]가 發刊되기도 했다.

本報에서는 第 I 報에서 說明한 바 있는 模型化나 氣泡에 관한 論文 以外의 重要文獻을 대략 分類해서 뒷면에 記載하고 流動層操作上으로 보아 特殊한 것 몇개의 特性을 살펴보고자 한다.

2. 流動化機構 및 熱—物質傳達

流動化開始速度는 流動層反應器 操作上 기본적인 것이지만 그 測定이 그리 容易하지는 않다. 특히 石炭燃燒 또는 氣體化 反應裝置, 기타 熱分解裝置로서 流動層을 應用하려니 高溫 高壓下에서 操作하게 되며 粒子直徑과 比重差가 있는 混合系를 處理하게 되므로 이 流動化開加速度는 큰 영향을 주는 因子가 되고 있는 것이다. Rowe[25,28]는 多成分系粒子混合物의 流動化開始速度를, 그中 큰 粒子의 重量分率을 기준으로理論式을 제안하였고 Barnea-Mednick[21]는 Barnea-Mizrahi[22] 相關式에 混合系中 各粒子別 體積分率을 고려한 關係式을 제안한 바 있다. 高壓下의 流動化開始速度에 관하여는 Broughton[24] 및 Mii[39] 등의 硏究가 있다. Broughton은 流動化開始速度에 영향을 주는 원인은 分散板 上下의 溫度差에 의한 分級이라고 설명하고 있으나 더 正確한 實驗値가 必要한 실정이다. Brodhust-Becker[23]는 여러가지 因子를 바꾸어가며 다각적으로 시험하여 流動化開始速度보다는 氣泡發生最小速度를 기준으로 함이 더 有利하다고 발표한 바 있다. 白雲石 中에서 石炭을 燃燒할때, 어떤 廢棄物을 流動化되고 있는 모래中에 投入시켜 燒却시킬 때나, 粒子直徑과 密度가 큰 差가 있는 物質을 한꺼번에 流動化시킬 경우 層內에선 分級이 일어나게 된다. 이때 적당한 混合程度에 따라 裝置燃燒率을 크게 좌우하게 된다. 또 石炭으로 부터 생기는 灰分을 溢流除去 시키느냐 混合殘留케 하느냐 하는 것은 操作條件上의 문제일 것이다. 이 分級에 대하여는 Rowe[99]가 그 기초적 硏究를 시행하였고, jetsam (또는 flotsam)이란 새 用語를 사용하여 模型[94]을 제안한 바 있다. Chen-Keairns[93]는 石炭氣體化및 燃燒行程에 대해 광범위하게 시험한바도 있다. 이것은 마치 氣—液間의 相平衡과 유사하여 流動化狀態의 粒子層과 그것을 固定層으로 있게 할때의 粒子層 相互間의 平衡關係를 나타내는 흥미로운 結果를 얻었다. 多成分混合物에 대한 分級硏究[96,102]도 다소 있다.

傳熱에 관한 것은 單行本[1]뿐 아니라 Gutfinger-Abuaf[107], Mori[114], Sparrow et al[117], 및 Yoshida[20] 등의 레뷰가 있고 McGaw[130]는 횡단류 流動層 熱交換器內 傳熱을 다루었다. 그리고 Zabrodsky[120]는 層內表面間 傳熱을 다룬 바 있다. 物質傳達에 관하여는 Yokota[136], Yoon-Thodos[138] 등이 발표한 바 있고, Dwivedi-Upadhyay[139]는 지금까지 발표된 재료를 재분석하고 상관관계식을 구하여 폭넓게 이루었다.

飛末流出[139~144], Slugging[156~161], 噴流層[162~179]에 대한 것은 뒷面에 分類된 참고문헌을 보기바란다. 分散板에 있어서는 氣泡徑과 관련되므로 設計上[150,151,366] 대단히 중요하다.

3. 流動層의 物理的 應用

중요한 것으로는 乾燥에의 應用[205,206,208,211,225], 被覆, 凝集, 造粒에의 應用[212,215,218~224,227,229], 및 熱交換에의 應用[209,211,217,220,226,231] 등으로 볼 수 있다. Krause, Slanky의 硏究는 放射性廢棄物에의 應用이고, Keairns는 高速增殖爐의 冷却에 쓰인 高溫 Na의 熱回收方法에 대한 硏究로서 傳熱係數가 2,000kcal/m^2.hr.°C 以上인 것으로 報告되였다. 그리고 Donsi-Russo는 流動層을 急速冷却器로 쓸 수 있음을 시사하였다.

4. 石炭—油類燃燒 및 固體廢棄物 處理에의 應用

서론에서 논한 바와 같이 이 계통의 論文이 압도적으로 많다. 그 內容에 따라 보면 燃燒[232~238], 脫黃이나 再生[239~242] 분야의 硏究가 대부분이다. 石炭의 氣體化관계는 Kunii[252], Osa[256] 및 Perry[257] 등의 硏究가 있고 重質油의 氣體化에 있어서는 Klass[264]의 解說이 있다. 氣體燃燒를

취급한 것은 Davis[233]와 Singh[237] 뿐이다. 流動層보일러의 材質에 관한 論文은 Cooke[243], Goldberger[244] 및 McNab[245] 등이 있다. 그리고 Thring[238]은 Stirling 熱機關에 熱源의 공급 방법으로서 傳熱係數가 높고 (400~750W/m²·°k), 等溫 (850~1100°C) 操作이 가능한 流動層燃燒에 대한 硏究에서 模型化와 應用可能性을 보였다.

固體廢棄物處理에 관한 것은 集塵, 타이어[303], 프라스틱[304,309,312], 스러지[305,313] 등의 工業廢棄物處理時 熱의 回收利用에 관한 것이 대부분이다. 그리고 Robert-Yates[239]는 연도까스내 SO_2를 除去하는데 應用하기도 하였다.

5. 冶金에의 應用 및 流動層電極

流動層反應器는 鑛石分離에 대단히 有利함으로 鑛石의 乾燥, 煆燒, 焙燒, 抽出 및 精製등의 분야에 광범위하게 應用되여지고 있다. Doheim[281]가 이 분야의 全般的인 利用에 대한 解說을 하였다.

鐵鑛石還元에의 應用[279,290,291,292] 및 우라늄 製鍊에의 應用[272,273,286]이 중요한 것들이다. HIB나 FIOB 工程[300]은 각각 年間 100萬ton, 40萬ton 규모로 제철공장이 운전되고 있다. 그리고 石灰石의 分解, 모리브데나이트 焙燒[285,280], 일메나이트의 鹽素化[299], 電導性流動粒子間 電極挿入으로 直接加熱에 의한 金屬製鍊[282,294], 活性炭의 賦活[297], 觸媒再生[302] 등의 硏究를 볼 수 있다.

그리고 流動層電極[343~359]에 관한 것은 前報에서 설명되였으나 그 文獻의 소개가 未洽하여 더 추가한다.

6. 특수流動層의 特性

a. 眞空流動層

氣體流動層이 거의 모두 常壓下에서 操作되지만 減壓下에서 操作하게 되면 熱에 민감해 져서 流動化, 壁—粒子間의 傳熱 및 粒子—流體間의 物質移動에 관한 特性이 增大된다는 사실에 근거를 둔 減壓狀態를 眞空流動層이라 한다.

減壓下에서의 流體의 거동은 常壓下 操作에서나 거의 같으며 流動化効率은 形狀係數, 粒子徑이 적을 수록 나쁘고 공급되는 氣體의 流動化에는 영향을 받지 않는다. 각粒子의 流動化効率은 表1.에 나타냈다.

표 1. Efficiency of fluidization[305]

Samples	Avg. Particle dia. (mm)	Efficiency
Glass bead	0.108	0.27
〃	0.226	0.25
〃	0.295	0.20
Glass powder	0.115	0.52
〃	0.214	0.44
〃	0.289	0.36
Sand	0.239	0.26
〃	0.327	0.23
Coke powder	0.259	0.28
Al powder	0.196	0.39
Acryl powder	0.083	0.56

眞空流動層에서 壁—粒子間의 傳熱特性에 영향을 미치는 因子에 대해 살펴보면 다음과 같다

i) 最少安定化流量

그림 1에서 보는 바와 같이 壁—層間의 傳熱係數는 $\frac{G}{G_{mf}}\geqq 10$ 범위에서는 거의 일정한 값을 가지나 $\frac{G}{G_{mf}}<10$ 범위에서는 流量이 적어짐에 따라 傳熱係數, h_w도 감소한다.

ii) 壓力의 영향

h_w는 壓力이 낮아짐에 따라 감소한다. 그 이유는 壓力이 낮은 범위에서 流體가 粘性이 變해서 유효한 $\frac{G}{G_{mf}}$가 감소하기 때문에 流動化狀態가 劣化하여 h_w가 현저한 감소를 나타낸다. 壓力이 낮아지면 $\frac{G}{G_{mf}}\leqq 1$로 떨어지게 되며 따라서 $h_w\leqq 10$ 정도로 낮아진다.

iii) 粒子徑의 영향

常壓에서 h_w에 대한 粒子徑의 영향은 Vreedenburg[2]의 실험결과에 따르면 다음과 같다.

$$h_w \propto d_p^{-0.56}$$

iv) 氣相의 영향

h_w에 기여하는 因子로는 粒子—粒子間, 粒子

壁間, 粒子—氣體間, 壁—氣體間의 傳熱, 輻射등을 생각할 수 있다. 이와 같은 특성을 살려 粒子의 乾燥나 流動化粒子를 傳熱媒體로한 沈澱物의 乾燥에 利用할 수 있으며, 특히 신속한 氣相分解反應, 固體熱分解反應등에 應用可能하지만 減壓裝置로 인한 操作上의 문제점이 있게 된다.

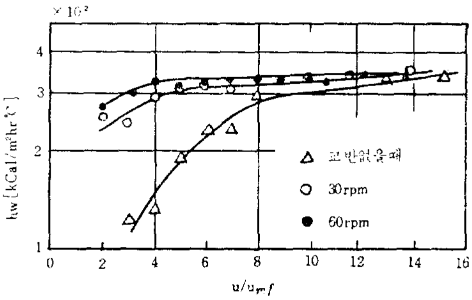


그림 1. h_w vs. U/U_{mf}[305]

b. 充塡流動層

氣體流動層이 傳熱係數가 크고 層內에서의 粒子의 供給과 排出이 용이하다는 장점을 지니고 있지만 流動化 氣體의 대부분이 層內에서 氣泡로서 上昇하기 때문에 粒子와의 接觸이 나쁠 뿐만 아니라 氣泡徑 및 그 上昇速度가 流動層의 內徑과 分散板의 構造, 層高, 氣體流速, 粒子徑 및 그 密度등에 크게 영향을 받기 때문에 層內에서의 流體의 거동을 파악하기 어렵고 裝置를 擴大化하는데 곤란하다. 이런 缺點을 보완하고 장점만을 有效하게 利用하기 위해 層內에 여러 형태의 充塡物을 넣어 그 빈틈에서 粒子가 流動化하여 氣泡의 合致成長을 막고, 粒子—流體間의 接觸을 원활하게 할 수 있을 뿐더러 層內에서의 粒子 및 流體의 흐름이 정상화되어 裝置의 擴大化가 용이하다.

또한 氣泡成長이 비교적 작기때문에 層內徑에 비하여 層高가 큰 경우에도 다른 流動層에서 보이는 Slugging 현상이 나타나지 않고 氣體流速의 증가와 더불어 均一하게 팽창한다. 充塡物의 直徑은 層內의 粒子混合에 큰 영향을 주는데, 이것에 대해서는 半徑方向과 軸方向에 대해서 많은 研究가 報告되어 있다.

充塡流動層內에서의 有効熱傳導度값은 固定層에 비해서는 500배 이상 크지만 일반 流動層에 비해선 작은 경향이 있으나 挿入充塡物의 直徑에 의해 그 값이 변한다. 熱傳達特性은 一般流動層과 유사한 경향을 가지며 동일粒子, 동일流動化氣體速度에서의 熱傳達係數는 一般流動層의 약 50～75% 정도의 값이 된다.

充塡流動層에서도 一般流動層과 같이 氣泡相과 濃厚相이 存在하나 層內에서의 氣泡는 充塡物에 의해 그 크기가 제약받기 때문에 氣體流速을 증가시키면 그數와 上昇速度만이 증가되어 一般流動層에서 사용되는 hydrodynamic flow model을 적용할 수 없어 流體—粒子間의 정확한 模型을 세우기 위해서는 대략 다음과 같은 假定을 하고 있다.

i) 層內에서 氣泡相과 濃厚相이 存在한다.

ii) 氣泡相은 plug flow한다.

iii) 濃厚相에서의 氣體는 完全混合 또는 다른 여러조건(前報의 表참고)으로 간주한다.

iv) 二相間에는 各 相內의 濃度差(즉分子擴散)에 의한 傳達과 相間交換係數(前報참고)로 표시되는 항에 따라 物質傳達이 일어난다.

v) 層內에서의 氣泡體積은 層팽창에 의해 증가한 것과 같다고 본다.

이와 같은 充塡流動層은 固定層과 流動層의 中間性質을 나타내는데 充塡物의 크기와 形狀을 바꿈으로서 裝置的特性을 살릴 수 있어 각종 工業에 應用되고 있다.

c. 攪拌流動層

反應速度가 느린物質을 流動層에서 合成, 酸化, 또는 還元하는 경우 傳換率이 低下되는데 이를 올리기 위해 氣體流速을 줄이면 정상적 流動化가 안되기 때문에 곤란하다. 이런 경우 氣體의 最小流動化速度 부근이나 그 以下에서 攪拌器를 부착시켜 攪拌하며 反應시킬 경우 보다 큰 傳換率을 얻을 수 있을 뿐더러 다음과 같은 利點을 갖고 있다.

i) 多樣한 粒子의 觸媒를 使用할 수 있다.

ii) 觸媒全部가 反應에 기여하기 때문에 (dead zone이 감소) 反應率이 증가한다.

iii) 操作하는 도중에 觸媒交替가 용이하다.

iv) 均一溫度 유지할 수 있다

v) channeling을 방지하고 攪拌低抗을 줄일수 있다.

또한 吸濕性이 큰 부착성粉體나 處理도중 凝集되기 쉬운 粒粉體를 處理할 때도 마찬가지로 操業을 용이하게 하기 위해 기계적으로 粉粒子의 分散을 조장하는 攪拌器가 필요하다.

Kawabata[251]의 技術報告에 보면 攪拌流動層을 이용하여 石炭을 乾留하는데 應用한 바 있다 그림 2에 표시한 바와 같이 流動化空氣中의 酸素의 未反應率 $\frac{C}{C_0}$와 空氣平均滯在時間 $\theta_g\left(=\frac{H_f}{u_0}\right)$와의 관계를 나타냈는데 퍽 유리한 것으로 생각된다.

이와 같은 攪拌流動層에 의해 이제까지 연속조업이 不可能하던 粉鐵鑛石의 還元, 粘結性物質의 乾燥, 石炭의 乾留, 廢棄發의 燒却등에 널리 應用되리라 본다.

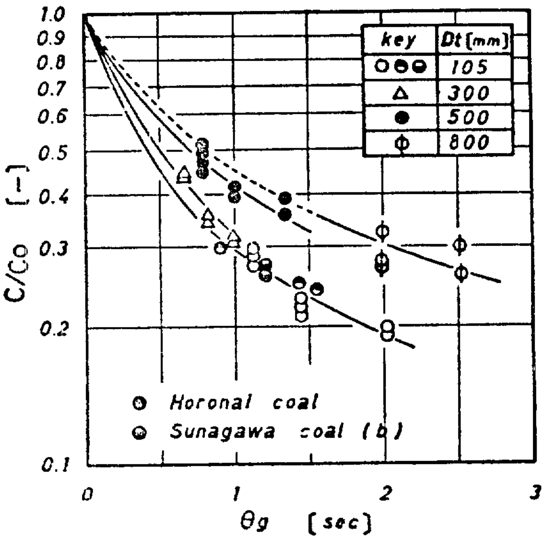


그림 2. Relationship between $\frac{C}{C_0}$ vs. θg

d. 振動流動層

보통流動層 反應器에서 流動化 시키기 어려운 粒子를 다루는 경우 振動과 衝擊을 加해주면 流動化狀態가 向上되고, 最小流動化速度를 줄일 수 있으며 粒子—流體間의 熱 및 物質傳達을 증진시키며 層과 기벽간의 傳熱도 향상시킬 수 있다. 다음 그림 3은 流動層에 振動을 加했을 때와 加하지 안했을 경우 氣體流速과 傳熱係數와의 관계를 나타내고 있는데 流動化 開始速度以下에서 이미 固定層보다 훨씬 큰 傳熱係數를 나타내고 있다.

또한 加振에 의해 加熱面 부근에 있는 粒子의 更新速度가 증가하여 流動이 활발해지고 層팽창이 비교적 작기 때문에 加熱面에서의 粒子密度가 氣體流速을 크게 하드라도 감소하지 않아 振動强度의 증가에 의해 傳熱係數가 현저하게 커진다.

振動流動層乾燥器의 경우 드럼乾燥器性能과 비교해 보면 表2에서 보는 바와 같이 그 性能이 월등함을 알 수 있다.

振動流動層에서는 기계적진동을 加할때 材料의 강도및 장치를 고려해야하는 문제점이 있으나 濕潤性粒子와 같은 難流動性 物質의 流動化를 촉진시키는데 利用할 수 있으며 加振에 의해서 粒子의 운동이 활발하기 때문에 乾燥를 목적으로 하는 경우 局部加熱을 막을 수 있다. 또한 層內에 脈動流가 생김으로서 粒子—流體間의 相

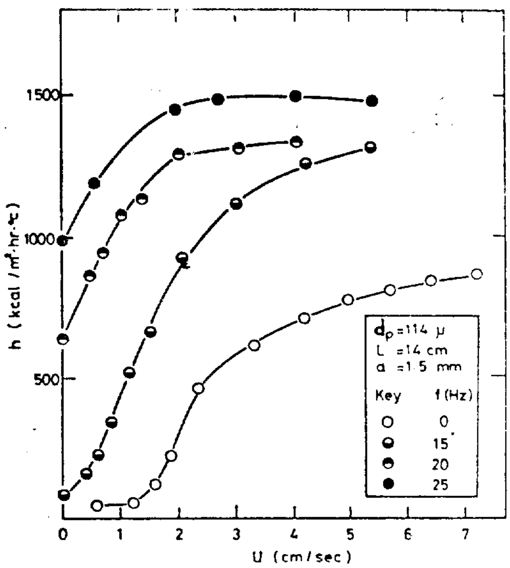


그림 3. Comparison of heat transfer coefficient in vibro-fluidized bed and in fluidized bed[202]

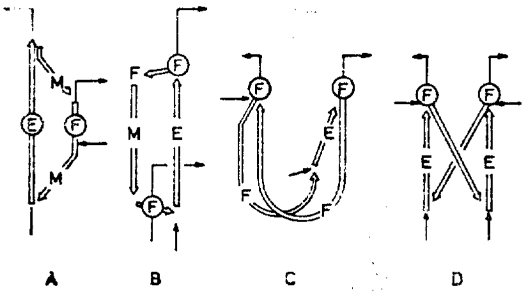
표 2. **Comparative characteristics of drum type drier and vertical vibro-drier**[2)]

Characteristics	Drier	
	Drum	Vibro-FB
Drying time, min	20	4
Electric power Consumption, KWH /ton	2.21	1.77
Moisture removed from $1m^2$, kg/hr	0.61	2.66
Specific heat consumption, kcal/kg H_2O	1500	850

對速度가 증가하기 때문에 傳熱 및 物質傳達速度가 증가하는 利點이 있다.

e. 循環流動層

최근 석유자원의 有効使用과 완전 脫黃이 사회적인 관심사가 되고 있는데 이런 문제를 완전히 해결하기 위한 시도로서 각종 原油, 殘渣油 및 重質油의 熱分解와 氣體化에 대한 연구가 성행되고 있다. 이에 적합하고 유리한 것중의 하나가 循環流動層이다. 이는 대개 二室流動層을 적당히 조합하여 한 系를 이루는데, 이系內에는 移動層(M), 流動層(F), 그리고 氣流輸送層(E) 部分이 있게 된다. 그림 4에 기존 공업적 循環系를 간단히 표시했다. 重質油를 熱分解하여 Olefins類를 제조한다고 생각 할때 反應時間이 짧아야하고 生成氣體를 急冷해야 하는데 이럴경우 이 循環流動層系가 비교적 적합함을 알 수 있다



A: Lurgi's sand cracker
B: UOP's FCC unit
C: ERE model Ⅳ FCC unit
D: BASF fluidized flow process
White circles mean the main reacting zones

그림 4. Schematic diagram for various circulation[146)] systems in practical application

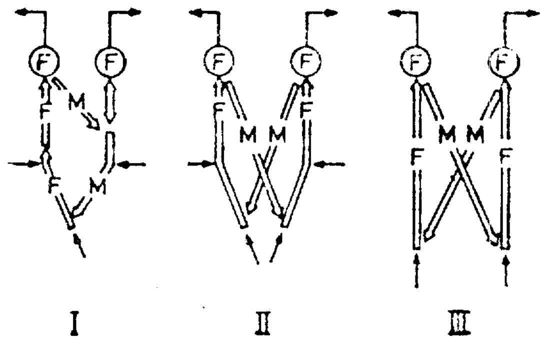


그림 5. **Schematic diagram of circulation systems**

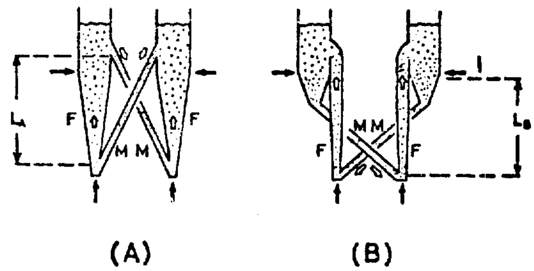


그림 6. **Two possible systems for No. Ⅲ in Fig. 5.**

Kunii[146)]가 소개한 流動層—移動層을 조합한 三個의 系를 그림 5에 표시했다. 그리고 그림 6는 그림 5에 표시한 Ⅲ형循環系를 나타냈다.

固體循環系는 이온교환수지 재생, 觸媒의 재생, 熱交換器등 그 應用이 다양하리라 생각된다

7. 結　言

流動層反應器를 고려할때 分散板設計, 內挿物形狀의 效果, 流動粒子와 壁面間摩耗, 高溫流動層에서의 濕度와 粒子間引力 등 해결하여야 할 과제가 많은 것이다. 이를 위하여 模型을 기초로 어느정도의 流動層反應器 履歷을 파악하고 좀더 계통적실험에 의한 신뢰할만한 實測値가 集積되어져야만 하겠다.

Literatures of Fluidized Beds

A. Books and Proceedings

1. J. S. M. Botterill, Fluid-Bed Heat Transfer, Academic press (1975).
2. J. F. Davidson and D. Harrison, Fluidization, Academic press (1971).
3. D. L. Keairns, Fluidization Technology, Vol 1 and 2, Hemisphere pub. (1976).
4. K. B. Mathur and N. Epstein, Spouted Beds, Academic press (1974).
5. Coal Gasification, Advances in Chem. Ser., No. 131, Amer. Chem. Soc. (1974).
6. Proceedings of the 5th European, 2nd Int. Sym. on Chem. Reaction Engng., Amsterdam, Elsevier Pub. Co. (1972).
7. Proceedings of the Int. Sym. on Fluidization and its Application, Toulouse, Cepadues-Editions (1973).
8. Proceedings of Int. Sym. on Fluidized Combustion, London, Vol. 1 and 2, Inst. of Fuel Sym. Ser., 1 (1975).
9. Proceedings of Int. Sym. on Fluidized-Bed Combustion, McLean, Virginia, MITRE Corp. (1975).
10. Fluidization, Fundamental Studies, Solid-Fluid Reaction and Application, *A. I. Ch. E. Sym. Ser.*, **67** (1971), No. 116.
11. Fluidized Bed Fundamentals and Application, *A. I. Ch. E. Sym. Ser.*, **69** (1973), No. 128.
12. Fluidization and Fluid-Particle System, *A. I. Ch. E. Sym. Ser.*, **70**(1974), No. 141.
13. Chemical Application in Solid Waste Treatment, *A. I. Ch. E. Sym. Ser.*, **68** (1972), No. 122.
14. Air Pollution and its Control, *ibid*, **68** (1 972), No. 126.
15. Declining Domestic Reserves-effect on Petroleum and Petrochemical Industry, *ibid*, **69** (1973), No. 127.
16. Recent Advances in Air Pollution Control, *ibid*, **70** (1974), No. 137.
17. Optimum use of World Petroleum, *ibid*, **70** (1974), No. 142.
18. Coal Processing Technology, CEP Technical Manual, Vol. 1 and 2 (1974).
19. Proceedings of 1st Int. Conf. on Conversion of Reuse to Energy, Montreux (1975).
20. K. Yoshida, Fluidization (Review), *Kagaku Kogaku*, **40** (1976), 653.

B. Mechanism of Fluidization

B-1. Incipient and bubbling velocities.

21. E. Barnea and R. L. Mednick, Correlation for min. fluidization velocity, *Trans. Instn. Chem. Engrs.*, **53** (1975), 278.
22. E. Barnea and J. Mizrahi, *Chem. Eng. J.*, **5** (1973), 171.
23. T. E. Broadhurst and H. A. Becker, *A. I. Ch. E. J.*, **21** (1975), 238.
24. J. Broughton, Influence of bed temp. and particle size distribution on incipient fluidization behaviour, *Trans. Instn Chem. Engrs.*, **52** (1974), 105
25. L. Cheung, et al, Min. fluidization velocity of a binary mixture of different sized particles, *Chem. Eng. Sci.*, **29** (1974) 1301.
26. T. Otake, et al, *J. Chem. Eng. Japan*, 8 (1975), 388.
27. S. Mori and A. Moriyama, Criteria for uniform fluidization of the non-aggregative particles, *Kagaku Kogaku Ronbunshu*, **3** (1 977), 7.
28. P. N. Rowe and A. W. Nienow, Min. fluidization velocity of multi-comp. particle mixtures, *Chem. Eng. Sic.*, **30** (1975), 1 365.
29. B. Singh, et al, Measurement of min. fluidization at elevated temp., *Trans. Instn*

Chem. Engrs., **51** (1973), 93.

B-2. Interparticle forces

30. G. Donsi, et al, Solid-solid interaction between particles of a fluid bed catalysist, *Chem. Eng. Sci.*, **30** (1975), 1533.
31. K. Rietema, The effect of inter particle force on the expansion of a homogeneous gas-fluidized bed, *ibid*, **28** (1973), 1493.
32. K. Rietema, Fluidization Technology, Vol 1 (1976), pp. 53.

B-3. Hydrodynamical properties

33. A. E. Fouda and C. E. Capes, Hydrodynamic particle volume and fluidized bed expansion, *Can. J. Chem. Eng.*, **55** (1977), 386.
34. J. Guedes de Carvalho and D. Harrison, Fluidized Combustion Conf., London, *Inst. Fuel Sym. Ser.*, Vol B1 (1975).
35. R. D. Jolly and I. D. Doig, An examination of the net pressure drop in fluidized beds spontaneous osillation of a gas-fluidized bed, *Chem. Eng. Sci.*, **28** (1973), 971.
36. K. W. Lange and H. Rees, *Arch. Eisenhüttenwesen*, **43** (1972), 539.
37. J. Medlin and R. Jackson, Fluid mechanical description of fluidized bed, *IEC Fundamentals*, **14** (1975), 315.
38. J. M. D. Merry and J. F. Davidson, "Gulf stream" circulation in shallow fluidized beds, *Trans. Instn. Chem. Engrs.*, **51** (1973), 361.
39. T. Mii, et al, *J. Chem. Eng. Japan*, **6** (1973), 10.
40. H. Ritsmann and K. Schügerl, The influence of the scale-up on the local rheological properties of gas-fluidized beds, *Chem. Eng. Sic.*, **29** (1974), 427.
41. Thomas H. Hsiung and G. Thodos, Expansion chracteristics of gas-fluidized beds, *Can. J. Chem. Eng.*, **55** (1977), 221.
42. M. Bafrnec and J. Bena, Quantitative data on the lowering of electrostatic charge in a fluidized bed, *Chem. Eng. Sci.*, **27** (1972), 1177.
43. T. W. Johnson and J. R. Melcher, Electromechanics of electrofluidized beds, *IEC Fundamentals*, **14** (1975), 146.
44. E, K, C, Yuan, et al, Arcing at electrode surface in fluidized beds, *Trans. Instn Chem. Engrs*, **53** (1975), 41.

B-4. Transition between particlulate and aggregative states.

45. D. E. Creasy, *Powder Technology*, **7** (1973), 353,
46. J. A. H. Jong and J. F. Nomden, *ibid*, **9** (1974), 91.
47, K. Doichev, Intergetic aspects of the transition between aggregative and particulate fluidization, *Chem. Eng. Sci.*, **29** (1974), 1205.
48. K. Doichev, et al, *ibid*, **30** (1975), 419.
49. P. M. Heertjes and J. Verloop, Übergan von homogener zu hetrogener fluidization, *Chemie-Ing-Tenchn.*, **45** (1973), 379.

B-5. Stabilities and pressure fluctuations.

50. M. H. I. Baird and A. J. Klein, Spontaneous oscillation of a gas-fluidized bed, *Chem. Eng. Sci.*, **28** (1973), 1039.
51. G. P. Cherepanov, On the theory of fluidization, *IEC Fundamentals*, **11** (1972), 9.
52. R. Clift, et al, Stability of bubbles in fluidized beds, *ibid*, **13** (1974), 45.
53. M. M. El-Kaissy and G. M. Homsy, Instabilites waves and the origin of bubbles in fluidized beds, *Int. J. Multiphase*, **2** (1976), 379.
54. M. T. Hoath and R. Collins, Proc. of Int. Sym. on Fluidization, Toulouse (1973), pp. 254.

55. R. Jackson, Fluidization Technology, Vol 1 (1976), pp. 49.
56. B.R.E. Jones and D.L. Pyle, *A.I.Ch.E. Sym. Ser.*, **67** (1971), 1.
57. M.J. Lockett and G. Gunnarsson, The delayed bubbling of gas fluidized beds, *Chem. Eng. Sci.*, **28** (1973), 666.
58. J. Medlin, Fluid mechanical description of fluidized beds convective instabilities in fluidized beds, *ICE Fund.*, **13** (1974), 247.
59. J. Verloop and P.M. Heertjes, On the origin of bubbes in a gas-fluidized beds, *Chem. Eng. Sci.*, **29** (1974), 1101.
60. T. Kato, et al, *Kagaku Kogaku Ronbunshu*, **2** (1976), 109.
61. T. Kato and I. Muchi, *ibid*, **2** (1976), 115.
62. R. Lirag, Jr and H. Littman, *A.I.Ch.E. Sym. Ser.*, **67** (1971), 11.
63. P.A. Taylor, et al, Proc. of Int. Sym. on Fluidization, Toulouse (1973), pp. 90.
64. J. Verloop and P.M. Heerjes, Periodic pressure fluctuation in fluidized beds, *Chem. Eng. Sci.*, **29** (1974), 1035.

C. Gas mixing and Hold-up

65. T.J. Evans and P.N. Rowe, Dispersion of gas in the track of the tracer bubbles injected into a two-dimensional fluidized bed, *Chem. Eng. Sci.*, **29** (1974), 293.
66. R.W. Fontaine and P. Harriott, The effect of molecular diffusion on mixing in fluidized beds, *ibid*, **27** (1972), 2189.
67. R.N. Ghar, et al, Calculate degree and time of mixing in fluid beds by quick method, *Process Eng.*, No**3** (1973), pp. 78.
68. B.M. Gibbs and M.G. Perry, *A.I.Ch.E. Sym. Ser.*, **67** (1971), 46.
69. R. Letan and J. C. Elgin. *Chem. Eng. J*, **3** (1972), 136.
70. A. Nazemi, et al, *A.I.Ch.E. Sym. Ser.*, **70** (1974), 98.
71. H.V. Nguyen and O.E. potter, Chem. React. Eng. II, *Adv. in Chem. Ser.*, No **133** (1974), pp. 290.
72. M.S. Nishinaka, et al, *Kagaku Kogaku Ronbunshu*, **1** (1975), 81.
73. P.N. Rowe and T.J. Evans, Dispersion of tracer gas supplied at the distribution of freely bubbling fluidized beds, *Chem. Eng. Sci.*, **29** (1974), 2235.
74. Y. Yaron, Regular expansion Solutions for heat or mass transfer in concentrated two-phase particulate systems at small Peclet and Reynolds numbers, *Int. J. Heat Mass Transfer*, **19** (1976), 61.
75. N. Yutani, et al, Characteristics of solids-holdup and fine particles concentration in fluidzed beds of binary particles system with particles entrainment, *Kagaku Kogaku Ronbunshu*, **3** (1977), 1.

D. Solid Mixing

76. S. Abrahami and W. Resnick, *Powder Technol.*, **6** (1972), 113.
77. S. Abrahami and W. Resnick, Fluidized bed behabior near incipient fluidization in a three-dimensional bed, *Trans. Instn Chem. Engrs*, **52** (1974), 80.
78. S.P Babu, et al, *A.I.Ch.E. Sym. Ser.*, **69** (1973), 49.
79. J. Baeyens and D. Geldart, Proc. of Int. Sym. on Fluidization, Toulouse (1973), pp. 182.
80. A.P. Baskakov, et al, Separation of materials in equipment with a fluidized bed and with continuous charging and discharging, *Int. Chem. Eng.*, **15** (1975), 286.
81. J.S.M. Botterill and D.J. Bessant, *Powder Technol.*, **8** (1973), 213.
82. G. Donsi, et al, *ibid*, **6** (1972), 217.
83. A.K. Hains, et al, The interrelationship

between bubble motion and solid mixing in a gas-fluidized bed, *A. I. Ch. E. J.*, **18** (1972), 591.

84. T. Hirama, *Kagaku Kogaku Ronbunshu*, **1** (1975), 272.
85. D. Kunii, et al, *ibid*, **4** (1978), 108.
86. S. M. Morooka, et al, Sedimentation velocity and expansion ratio of emulsion phase in gas-solid fluidized bed, *Kagaku Kogaku*, **37** (1973), 485.
87. M. Nishinaka, et al, *Powder Technol.*, **9** (1974), 1.
88. S. Ohshima, et al, Liquid mixing in gas-liquid cocurrent upflow through packed and fluidized particle bed, *Kagaku Kogaku Ronbunshu*, **3** (1977), 406.
89. G. M. Panchenkov, et al, Technique for studying mixing of Solid particles in a fluidized bed, *Int. Chem. Eng.*, **14** (1974), 105.
90. P. N. Rowe, Estimation of solids circulation rate in a bubbling fluidized bed, *Chem. Eng. Sci.*, **28** (1973), 979.
91. P. N. Rowe and A. W. Nienow, Min. fluidization velocity of muti-comp. particle mixture, *ibid*, **30** (1975), 1365.
92, K. Yoshida and C. Y. Wen, *A. I. Ch. E. Sym. Ser.*, **67** (1971), 151.

E. Segregation

93. J. L. P. Chen and D. L. Keairns, Particle size segregation in a fluidized bed, *Can. J. Chem. Eng.*, **53** (1975), 395.
94. L. G. Gibilaro and P. N. Rowe, A model for a segregation gas-fluidized bed, *Chem. Eng. Sci.*, **29** (1974), 1403.
95. K. Kato, et al, The characteristics of particle classification by a horizontal packed fluidized particle classfier, *Kagaku Kogaku Ronbunshu*, **3** (1977), 473.
96. E. Naveh and W. Resnick, Particle size segregation in baffled fluidized beds, *Trans. Instn Chem. Engrs*, **52** (1974), 58.
97. A. W. Nienow, A note on the log-like properties of gas fluidized beds, *ibid*, **51** (1973), 260.
98. N. Piccinini, et al, *Can. J. Chem. Eng.*, **55** (1977), 122.
99. P. N. Rowe, et al, The mechanism by which particles segregate in gas-fluidized beds, *Trans. Instn Chem. Engrs*, **50** (1972), 310.
100. M. Yamazaki, et al, Bubble size distribution in a fluidized bed by the hot-wire scope technique, *Kagaku Kogaku Ronbunshu*, **3** (1977), 473.
101. T. M. Beekmans and T. Tinh, Separation of mixed granular solids using the fluidized counter-current cascade principle, *Can. J. Chem. Eng.*, **55** (1977), 493.
102. R. T. Wakeman and B. W. Stopp, *Powder Technol.*, **13** (1976), 261.

F. Heat Transfer

F-1. Wall to bed

103. A. P. Baskakov and V. M. Pakhaluev, Investigation of the thermal Conductivity of a bed fluidized in the presence of banks of horizontal tubes, *Int. Chem. Eng.*, **13** (1973), 48.
104. A. P. Baskakov, et al, Proc. of Int. Sym. on Fluidization, Toulouse (1973), 293.
105. L. A. Behie, et al, Heat transfer from a grid jet a lage fluidized bed, *Can. J. Chem. Eng.*, **53** (1977), 25.
106. B. V. Berg and A. P. Baskakov, Investigation of local heat transfer between a fixed horizontal cylinder and a fluidized bed, *Int. Chem. Eng.*, **14** (1974), 440.
107. C. Gutfinger and N. Abuaf, *Adv. in Heat Transfer*, Vol **10** (1974), pp. 167.
108. N. F. Filippovskii and A. P. Baskakov, *Int. Chem. Eng.*, **13** (1973), 5.

109. J.D. Gabor, wall-to-bed heat transfer in fluidized beds, *A.I.Ch. E. J.*, **18** (1972), 249.
110. R. Yamajaki, et al, Heat transfer in vibro-fluidized bed, *J. Chem. Eng. Japan* **7** (1974), 373.
111. J. Kubie and J. Broughton, A model of heat transfer in gas fluidized bed, *Int. J. Heat Mass Transfer*, **18** (1975), 289.
112. H.K. Lese and R.I. Kermode, Heat transfer from a horizontal tube to a fluidized bed in the presence of unheated tubes, *Can. J. Chem. Eng.*, **50** (1972), 44.
113. V.K. Maskaev and A.P. Barkakov, Futures of external heat transfer in a fluidized bed of coarse particles, *Int. Chem. Eng.*, **14** (1974), 80.
114. S. Mori, *Kagaku Kogaku*, **37** (1973), 30.
115. L. Reh, Strömungs und Austauschverhalten von Wirbelschichten, *Chemie-Ing-Techn.*, **46** (1974), 180.
116. J.F. Richardson, et al, Heat transfer from immersed surfaces in liquid fluidized beds, *Chem. Eng. Sci.*, **31** (1976), 619.
117. E.M. Sparrow, et al, Heat transfer bibliography, *Int. J. Heat Mass Transfer*, **20** (1977), 279.
118. N.J. Syromyatnikov, The theory of external heat transfer in a fluidized bed, *Int. Chem. Eng.*, **14** (1974), 483.
119. K. Yoshida, et al, Mechanism of bed-wall heat transfer in a fluidized bed at high temperatures, *Chem. Eng. Sci.*, **29** (1974), 77.
120. S. S. Zabrodsky, et al, On fluidized bed-to-surface heat transfer, *Can. J. Chem. Eng.*, **54** (1976), 52.

F-2. Particl to fluid.

121. A.R. Balakrishanan and D.C.T. Pei, Fluid-particle heat transfer in gas-fluidized beds, *Can. J. Chem. Eng.*, **53** (1975), 231.
122. D. Bhattacharyya and D.C.T. pei, Fluid-to-particle heat transfer in fluidized beds, *IEC Fund.*, **13** (1974), 199.
123. S.C. Bhattachayya and D. Harrison, Heat transfer in a pulsed fluidized beds, *Trans. Instn Chem. Engrs*, **54** (1977), 281.
124. J. Broughton and J. Kubie, A note on heat transfer mechanism as applied to flowing granular media, *Int. J. Heat Mass Transfer*, **19** (1976), 232.
125. E.N. Ganic and W.M. Rohsenow, Dispersed flow heat transfer, *ibid*, **20** (1977), 855.
126. S.N. Gupta, et al, Fluid-particle heat transfer in fixed and fluidized beds, *Chem. Eng. Sci.*, **29** (1974), 839.
127. T. Hirama, et al, *Kagaku Kogaku Ronbunshu*, **3** (1977), 344.
128. G.A. Hughmark, Heat transfer in a fluidized bed of small particles, *A.I.Ch. E.J.*, **19** (1973), 658.
129. J. Kubie, Bubble induced heat transfer in gas-fluidized beds, *Int. J. Heat Mass Transfer*, **19** (1976), 144.
130. D.R. McGow, Heat transfer in shallow crossflow fluidized bed heat exchangers, *ibid*, **19** (1976), 657.
131. P.N. Rowe, Fluid-to-particle heat transfer in fluidized beds, *IEC Fund.*, **14** (1975), 281.
132. H. Schmidt, Bubble formation and heat transfer during dispersion of superheated steam in saturated water, *Int. J. Heat Mass Transfer*, **20** (1977), 635.
133. A.I. Tamarin, An investigation of the effective thermal conductivity of fluidized bed with a packing, *Int. Chem. Eng*, **15** (1975), 327.
134. N. Wakao, et al, Coefficient of axial

heat transfer in incipient fluidization, *Kagaku Kogaku Ronbunshu*, **3**, (1977), 515.

135. S. S. Zaborosky, at al, On fluidized bed-to-surface heat transfer, *Can. J. Chem. Eng.*, **54** (1976), 52.

G. Mass Transfer

136. S. Yokota, et al, *Kagaku Kogaku Ronbunshu*, **1** (1975), 399.

137. P. Yoon and G. Thodos, Mass transfer in the flow of gases through shallow fluidized beds, *Chem. Eng. Sci.*, **27** (1972), 1 549.

138. P. Yoon and G. Thodos, Gas-solid fluidized system, *A. I. Ch. E. J.*, **19** (1973), 625.

H. Elutriation

139. Dwivedi-Upadhyay, *IEC process Des. Dev.*, **16** (1977), 157.

140. A. B. Fournol, et al, Solids entrainment in a large gas-fluidized bed, *Can. J. Chem. Eng.*, **51** (1973), 401.

141. S. K. Guha, et al, Mechanism of elutriation from fluidized beds, *Can. J. Chem. Eng.*, **50** (1972), 602.

142. D. Harrison, et al, Suppression of particle elutriation from a fluidized bed, *Trans. Instn Chem. Engrs*, **52** (1974), 213.

143. H. Hoffmann and O. Molerus, Feinguta-ustrag aus Wirbelschichten, *Chemie-Ing-Techn.*, **47** (1975), 995.

144. T. N. Sycheva and E. V. Donat, Investigation of entrainment of solid particles from a polydisperse fluidized bed, *Int. Chem. Eng.*, **15** (1975), 346

I. Circulation of Solids

145. J. S. M. Botterill and D. J. Bessant, Proc. of Int. Sym. on Fluidization, Toulouse (1973), pp. 81.

146. D. Kunii, et al, *Kagaku Kogaku*, **37** (1973), 949.

147. W. C. Yang and D. L. Keairns, Two-dimensional recirculatory bed data with simulated heat transfer surface in the down comes, *IEC Process Des. Dev.*, **14** (1975), 259.

148. W. C. Yang and D. L. Keairns, Fluidization Technol., **2** (1976), pp. 51.

J. Distributors and Baffles

149. G. P. Kuchin, et al, Gas distributor for units employing a high temp. fluidized bed, *Int. Chem. Eng.*, **15** (1975), 636.

150. Y. Ikeda, Design method for distributor of fluidized beds, *Kagaku Kogaku*, **38** (19 74), 632.

151. L. S. Leung and B. F. Towler, *Powder Technol*, **8** (1973), 27.

152. V. M. Milonov, Design of gas distributing grids made of heat resisiant concrete for fluidized bed equipment, *Int. Chem. Eng.*, **12** (1972), 473.

153. A. R. Otero and R. C. Munoz, Fluidized bed gas distributors of bubble cap type, *Powder Technol.*, **9** (1974), 279.

154. G. A. Serviant, et al, Studies on grid leakage in gas fluidized bed, *Can. J. Chem. Eng.*, **50** (1972), 690.

155. S. S. Zabrodsky, Proc. of Int. Sym. on Fluidization, Toulouse (1973), 99.

K. Slugging Beds

156. J. Baeyens and D. Geldart, An investigation into slugging fluidized beds, *Chem. Eng. Sci.*, **29** (1974), 255.

157. T. E. Broadhurst and H. A. Backer, Fluidization Technol., Vol. **1** (1976), pp. 63.

158. D. Harrison, Fluidization Technol., vol **1** (1976), pp. 245.

159. P. W. K. Kehoe and J. F. Davidson, *A.*

I. Ch. E. Sym. Ser., **69** (1973), 34.
160. X. T. Nguyen and M. A. Bergougnou, Approximate correlation for fluidized bed density within the slug flow regime, *Can. J. Chem. Eng.*, **53** (1975), 102.
161. R. Yamazaki, et al, The analysis of slugging phenomea in fluidized beds, *Kagaku Kogaku Ronbunshu*, **1** (1975), 143.

L. Spouted Beds

162. G. Brunello, et al, The drying of barley malt in the spouted bed dryer, *Can. J. Chem. Eng.*, **52** (1974), 201.
163. R. Clift, et al, Gas and particle motion in jets in fluidized beds, *Int. J. Multiphase Flow*, **2** (1976), 549.
164. Z. B. Grbavcic, et al, Fluid flow pattern-mechanism spouting velocity and pressure drop in spouted bed, *Can. J. Chem. Eng.*. **54** (1976), 33.
165. A. Kmiec, Simultaneous heat and mass transfer in spouted beds, *ibid*, **53** (1975), 18.
166. C. T. Lim and K. B. Mathur, Residence time distribution of gas in spouted beds, *ibid*, **52** (1974), 150.
167. H. Littman, et al, Pressure drop and flowrate characteristics of a liquid phase spout-fluid bed at the min. spout-fluid flow rate, *ibid*, **52** (1974), 174.
168. U. Mann and E. J. Crosby, Modeling circulation of solids in spouted beds, *IEC Process Des. Dev.*, **11** (1972), 314.
169. U. Mann and E. J. Crosby, Cycle time distribution measurements in spouted bed, *Can. J. Chem. Eng.*, **53** (1975), 579.
170. K. B. Mathur and C. J. Lim, Vapor phase chemical reaction in spouted beds-theoretical model, *Chem. Eng. Sci.*, **29** (1974), 789.
171. K. B. Mathur and N. Epstein, Developments in spouted bed, *Can. J. Chem. Eng.*, **52** (1974), 129.
172. G. S. McNab and J. Bridgewater, The application of soil mechanics to spouted bed design, *ibid*, **52** (1974), 162.
173. A. Nagarkatti and A. Chatterjee, Pressure and flow characteristics of a gas phase spout-fluid bed and the mechanism spout-fluid condition, *ibid*, **52** (1974), 185.
174. M. Nishikawa, et al, Suspension of solid particles in solid-liquid spouted vessel, *Kagaku Kogaku Ronbunshu*, **1**(1975), 363.
175. N. M. Rooney and D. Harrison, Spouted beds of fine particles, *Powder Technol.*, **9** (1974), 227.
176. K. Takeda and H. Hattori, Modified type of spouted beds, *Kagaku Kogaku Ronbunshu*, **1** (1975), 149.
177. D. van Velzen, et al, Gas flow patterns in spouted beds, *Can. J. Chem. Eng.*, **52** (1974), 145.
178. D. V. Vukovie, et al, Pressure drop bed expansion and liquid holdup in a three phase spouted bed contactor, *ibid*, **52** (1974), 180.

M. Special Fluidized Beds-Packed Fluidized, Multi-staged etc.

180. P. G. Alfredson and I. D. Doig, Behaviour of pulsed fluidized beds-part I, Bed expansion; part Ⅱ, bed contraction, *Trans. Instn Chem. Engrs.*, **51** (1973), 232, 242.
181. N. Arai, et al, Heat transfer in multistage inclined fluidized beds, *Kagaku Kogaku*, **37** (1973), 379.
182. N. Arai and Y. Sugiyama, Axial mixing of particles in vibro-inclined fluidized bed, *ibid*, **38** (1974), 255.
183. B. Germa in and B. Claudel, *Powder Technol.*, **13** (1975), 115.
184. P. Guigon, et al, *A. I. Ch. E. Sym. Ser.*,

70 (1974), 63.

185. S.C. Jain and B.H. Chen, *ibid*, **67** (No. 116) (1971), 97.
186. G. Jimbo, Various fluidization technology, *Kagaku Kogaku*, **38** (1974), 2
187. K. Kato and U. Ito, The elutriation rate from a packed fluidized bed, *J. Chem. Eng. Japan*, **5** (1972), 144.
188. K. Kato, et al, Chem. React. Eng, **II**, *Adv. in Chem. Ser.*, No **133** (1974), pp. 290
189. K. Kato, et al, Fluidization Technology, vol **2** (1976), pp. 215.
190. S. Morooka, et al, overall capacity coefficient of mass transfer between bubble phase and emulsion phase in free and eight-step fluid beds, *Kagaku Kogaku Ronbunshu*, **2** (1976), 71.
191. X. T. Nguyen, et al, The distribution of solids between in baffled fluidized beds, *Can. J. Chem. Eng.*, **51** (1973), 573.
192. M. Nishinaka, et al, Gas bubble holdup and logitudinal dispersion of solid particles in multistage fluid beds, *Kagaku Kogaku Robunshu*, **1** (1975), 605.
193. M. Nishinaka, et al, Holdup distribution of bubbles in eight-step-fluid beds, *ibid*, **2** (1976), 96.
194. K. Papadatos, et al, Proc. of Int. Sym. on Fluidization, Toulouse (1973), pp. 175.
195. J. Raghuraman and Y. B. G. Varma, Residence time distribution of solids in multi-stage fluidized beds, *Chem. Eng. Sci*, **28** (1973), 305.
196. J. Raghuraman and Y. B. G. Varma, A stochastic model for residence time and contact time distributions of the gas in multi-stage fluidized beds, *ibid*, **29** (1974), 697.
197. J. Raghuraman and Y. B. G. Varma, An experimental investigation of the residance time distribution of solids in multi-stage fluidization, *ibid*, **30** (1975), 145.
198. G. K. Roy and P. S. Gupta, *Chem. Eng. J.*, **5** (1973), 191.
199. G. K. Roy and P. S. Gupta, Prediction of the packed bed height in gas-solid semifluidization, *IEC Process Des, Dev.*, **13** (1974), 219.
200. Y. Sugiyama, et al, Drying of solid particle in an inclined fluidized bed, *Kagaku Kogaku Ronbunihu* **1** (1975), 594.
201. S. Tone, et al, Residence time distribution of solids in stirred fluidized and moving beds, *J. Chem. Eng. Japan*, **5** (1972), 68.
202. R. Yamazaki, et al, Heat transfer in vibro-fluidized bed, *ibed*, **7** (1974), 373.
203. J. Yurshalmi, et al, The fast fluidized bed, *IEC Process Des. Dev.*. **15** (1976), 47.

N. Applications to Physical Operations

204. E. Y. Barsukov and D. M. Soskind, Jet pulverization of solid particles in fluidized bed apparatus, *Int. Chem. Eng.*, **13** (1973), 84.
205. A. P. Baskakov, et al, Investigation of the pneumatic transport of a solid heat transfer medium used for drying crystal hydrates in a fluidized bed appatus, *ibid*, **13** (1973), 20.
206. Z. Beran and J. Lutcha, Optimizing particle residence time in a fluidized bed dryer, *Chem. Engrs*, No **303** (1975), 678.
207. M. F. Bukareva, et al, The drying of finely dispersed powders in vibro-fluidized beds, *Int. Chem. Eng.*, **10** (1970), 384.
208. W. L. Davis Jr. and W. Glazier, *A. I. Ch. E. Sym. Ser.*, **70**, No. 141 (1973), 131.
209. B. R. Dickey, et al, Waste heat disposal via fluidized beds, *Chem, Eng. Progr.*, **70**

(1) (1974), 60.
210. G. Donsi, et al, Fluidized Combustion Conf., London, No. 1 (1975), B7.
211. E. Douglas and C. P. Sayler, *A. I. Ch. E. Sym. Ser.*, **67** (116) (1971), 201.
212. K. Harada, Particle growth of simultaneous coating and agglomeration in the fluidized bed, *Kagaku Kogaku*, **36** (1972), 1237.
213. H. Inazumi and T. Suzuki, Dehumidification of humid air in fluidized bed, *ibid*, **38** (1974), 54.
214. F. Kaiser, Fliessbettstrahlmühle, *Chemie-Ing-Techn.*, **45** (1973), 676.
215. J. Kaspar and M. Rosch, Eine neue Entwicklung auf dem Gebiet der Wirbelschicht-granulation, *ibid*, **45** (1973), 736.
216. K. Kato, et al, Process design for a packed fluidized bed catalytic reactors, *Kagaku Kogaku Ronbunshu*, **3** (1977), 338.
217. D. L. Keairns, et al, Fluidization Technology, vol. 2 (1973), pp. 569.
218. H. Krause, Die Verfestigung hoch radioaktiver Abfälle, *Chemie-Ing-Techn.*, **45** (1973), 658.
219. V. A. Kruglov, et al, Unsteady and steady state processes for granulation of complex fertilizers in fluidized bed, *Int. Chem. Eng.*, **14** (1974), 50.
220. D. R. McGow, *Powder Technol.*, **6** (1972), 159.
221. S. Mortensen and S. Hormand, Fluidization Technology, val 2 (1976), pp. 519.
222. Z. Ormos, et al, Proc. of Int. Sym. on Fluidiziation, Toulouse (1973), pp. 524.
223. Z. Ormos, B. Csukas and K. Pataki, Fluidization Technology, vol 2 (1976), pp. 545.
224. V. R. Phillips and N. Epstein, Growth of nickel sulfate in a laboratory-scale fluidized crystallizer, *A. I. Ch. E. J.*, **20** (1974), 678.
225. K. Rietema and J. Hoebink, Proc. of Int Sym. on Fluidization, Toulouse (1973), pp. 319.
226. G. Russo and L. Massimilla, Proc. of 5th Europ. Sym. on Chem. Reac. Eng., Amsterdam (1972).
227. N. A. Shakova, et al, Investigation of the granulation of ammonium nitrate in a fluidized bed under industrial conditions, *Int. Chem. Eng.*, **13** (1973), 658.
228. R. Siegel, Effect of distributor plate-to-bed residence ratio on onset of fluidized-bed channeling, *A. I. Ch. E. J.*, **22** (1976), 590.
229. C. M. Slanky, Radioactive waste management, *Chemtech*, No. 3 (1975), 160.
230. J. Werther, Significance of bubble coalescence for the design of gas-solids fluidized beds, *chemie-Ing-Techn.*, **48** (1976), 339.
231. N. Yamakoshi, et al, *Tetsu to Hagane*, **58** (1972), 1969.

0. Combustion of Coal and Oil

0-1. Combustion

232. M. M. Avedesian and J. F. Davidson, Combustion of carbon particle in a fluidized bed, *Trans. Instn Chem. Engrs*, **51** (1973), 121.
233. C. E. Davies and P. Eisenklam, Fluidized Combustion Conf., London, No. 1 (1975), A4.
234. A. P. Fraas, A fluidized bed Combustion system, *Chem, Eng. Progr.* **69** (3) (1973), 58.
235. H. B. Locke and H. G. Lunn, Clean heat and power cycles using fluidized combustion, *chem, Engrs.*, No. **303** (1975), 667.
236. I. Nagashima, et al, Carbonization of coal in continuous fluidized bed, *Kagaku Kogaku Ronbunshu*, **3** (1977), 236.
237. B. Singh, et al, Fluidized Combustion Conf., London, No 1 (1975), C5.

238. R.H. Thring, Fluidized bed combustion for stirling engine, *Int. J. Heat Mass Transfer*, **20** (1977), 911.

0-2. Desulfurization and Regeneration

239. R.J. Best and J.G. Yates, Removal of sulfurdioxide from a gas stream in a fluidized bed reactor, *IEC Process Des. Dev.*, **16** (1977), 347.
240. B.R. Hubble, et al, 4th Int. Conf. on fluidized bed Comb., Virginia (1975).
241. D.L. Keairns, et al, Fluidized Combustion Conf., London, No 1 (1975), D1.
242. R.B. Snyder, et al, 4th Int. Conf. on fluidized bed comb., Virginia (1975).

0-3. Materials of Boiler

243. M.J. Cooke and E.A. Rogers, Fluidized Combustion Conf., London, No 1 (1975), B6.
244. W.M. Goldberger, *A.I.Ch.E. Sym. Ser.*, **70** (141) (1974), 88.
245. A.J. McNab, Design and materials requirement for coal gasification, *Chem. Eng. Progr.*, **71** (11) (1975), 51.

P. Gasification of Coal and Oil

P-1. For Coal

246. J.L. Beeson, et al, Hydrogen from coal tar in a continuous electrofluid reactor, *IEC Process Des. Dev.*, **13** (1974), 159.
247. A.E. Cover, et al, Kellogg's coal gasification process, *Chem. Eng. Progr.*, **69** (3) (1973), 31.
248. S.T. Gasior, et al, Fluidized bed gasification of various coals, *ibid*, **71** (4) (1975), 89.
249. R.J. Grace, et al, Gasification of lignite by B.C.R. two-stage super-pressure process, *IEC Process Des, Dev.*, **11** (1972), 95.
250. W.P. Hegarty and B.E. Moody, Evaluating the bi-gas S.N.G. Process, *Chem. Eng. Progr.*, **69** (3) (1973), 37.
251. J. Kawabata, et al, Low temp. carbonization of coal in stirred fluidized bed, *kaga ku kogaku*, **36** (1972), 788.
252. D. Kunii, *J. Japan Petrol. Inst.*, **17** (1974), 857.
253. P.H. Kydd, Integrated gasification gas turbine, *Chem. Eng. Progr.*, **71** (10) (1975) 62.
254. B.S. Lee, Slurry feeding of coal gasifiers, *ibid*, **71** (4) (1975), 81.
255. J. McMahon, Fluidized bed hydrogenation process for S.N.G., *ibid*, **68** (12) (1972), 51.
256. T. Osa and T. kunug, *J. Japan Petrol. Insi.*, **17** (1974), 869.
257. H. Perry, Coal conversion technology, *Chem. Eng.*, **81** (7) (1974), 88.
258. A.H. Pulsifer and T.D. Whealock, Production of hydrogen from coal tar in an electrofluid reactor, *IEC Process Des. Dev.*, **11** (1972), 229.
259. K.S. Rao, L. kota and R. Vaidyeswaran, Iron separator by hyperfiltration through changed membranes, *ibid*, **11** (1972), 226.
260. L.T. Scotti, et al, The project COED pilot plant, *Chem, Eng. Progr.*, **71** (4) (1975), 61.
261. H.A. Shearer, The COED process plus char gasification, *ibid*, **69** (3) (1973), 43.
262. J. Yerushalmi, et al, The fast fluidized bed, *IEC Process Des. Dev.*, **15** (1976), 47.

P-2. For Oil

263. B. Dutkiewicz and P.H. Spitz, Producing S.N.G. from crude oil and naphtha, *Chem. Eng. Progr.*, **68** (12) (1972), 45.
264. D.L. Klass, Synthetic crude oil from shale and coal, *Chem. Tech.*, No 8 (1975), 499.
265. D. Kunii, et al, Thermal cracking of

crude oil in fluidized bed with annular section, *Kagaku Kogaku*, **38** (1974), 68.
266. D. Kunii, et al, Thermal cracking of clude oil in circulation system of fluidized beds, *ibid*, **38** (1974), 74.
267. P. A. Lawrance, Entschwefelung von Heizöl, *Chemie-Ing-Techn.*, **45** (1973), 1141.
268. R. A. Newby, et al, Residual oil gasification and desulfurization, *Chem. Eng. Progr.*, **71** (5) (1975), 77.
269. H. Nishizaki and K. Endoh, Effect of oxygen concentration thermal decomposition of polystyrene in fluidized bed, *Kagaku Kogaku Ronbunshu*, **3** (1977), 219.
270. A. M. Squires. Die Bindung von Schwefel bei der Energieerzeugung. *Chemie-Ing-Techn.*. **44** (1972). 1.

Q. Mettallurgical Reactions

271. Anonymous. The upgrading of ilmenite ore to synthetic rutile. *Process Technol. Inst.*, **18** (11) (1973), 417.
272. W. J. Bjorklund and G. F. Offutt. Fluidized bed denitration of uranyl nitrate, *A. I. Ch. E. Sym. Ser.*, **69** (128) (1973), pp. 123.
273. L. C. Borduin, et al, Uranium recovery from graphite based fuels by fluidized combustion, *ibid*, **69** (128) (1973), pp130.
274. N. F. Boyd, Coal conversion processes loom big as a source of hydrocarbon fuels, *Miner. Eng.*, **26** (9) (1974), 34.
275. M. I. Brittan, Fluidized bed copper chloridizing, *Trans. Inst. Min. Met.*, **80** (1971), C262.
276. D. E. Creasy, *Br. Chem. Eng.*, **16** (1971), 605.
277. J. C. Daley, Fluosolids roasting practice at copperhill operations, 10th Annu. AIME Meet (1976), Las Vesgar, Calif.
278. M. A. Doheim, et al, Chlorination of hightitania slag in fluidized beds, *Trans. J. Inst. Metal.*, **14** (16) (1973), 483.
279. M. A. Doheim, Fluidiziation in the ferrous industry, *Iron Steel Inst.*, **47** (5) (1974), 405.
280. M. A. Doheim, et al, Fluidized bed roasting of molybdenite, *Trans. Inst. Min. Metal.*, **48** (1975), C111.
281. M. A. Doheim, Fluidization in the nonferrous mineral processing and metal industry, *Int. J. Min. Proc.*, **3** (1976), 313.
282. F. W. Dorn, Gewinnung von phosphor im Elektrofliessbettofen, *Chemie-Ing-Techn.*, **45** (1973), 1013.
283. G. H. Geiger, et al, Rapid quenching in a water fluidized bed, *Met. Eng. Q.*, **13** (2) (1973), 18.
284. D. R. George, et al, A countercurrent column for fluid bed ion exchange for uranium ore slurries, Met. Soc., 102 AIME Meet (1973), Chicago.
285. A. I. Golant, et al, Quality and effectiveness of controlling the temperature of the fluidized bed roasting of molybdenite concentrates, *Tsventn, Metal*, **43** (3) (1970), 45.
286. V. Gonzalez and A. R. Otero, *Powder Technol.*, **7** (1973), 137.
287. A. W. Henderson, et al, Dechlorination of ferric chloride with oxygen, *Met. Trans.*, **3** (1972), 2579.
288. J. Hoebink and K. Rietema, Fluidized bed drying, proc. Int. Sym. Fluidization and its Applications, Toulouse (1973), pp 319.
289. G. W. Hogg and E. S. Grimmett, *A. I. Ch. E. Sym. Ser.* **67** (116) (1971), 190.
290. N. R. Iammartino, Direct-reduction roundup-I, *Chem. Eng*, **81** (8) (1974), 56.
291. N. R. Iammartino, Direct-reduction roundup-II, *ibid*, **81** (9) (1974), 36.
292. I. I. Inculet, et al, Electrostatic benificiation apparatus for fluidized iron and other

ores, *IEEE Trans. Ind. Appl.*, IA-**8** (6) (1972), 744.

293. Kondo, et al, Progress in Extractive Metallurgy (1973).

294. A.A. Manieh, D.S. Scott and D.R. Spink, Electrochemical fluidized bed chlorination of zircon, *Can. J. Chem. Eng.*, **52** (1974), 507.

295. R.C. Merritt, The extractive metallurgy of uranium, Colorado School of Mines Res. Inst. (1971). pp57.

296. S. Morooka, et al, characteristics of rectangular fluidized bed electrode reactors, *Kagaku Kogaku Ronbunshu*, **3** (1977), 320.

297. H. Murakami and T. Okamoto, *Kagaku Sochi*, **17** (1975), 38.

298. G.M. Obeldobel and D.E. Freshcorn, Particle behaviour in a commercial fluidized bed roaster, 105th AIME Annu. Meet (1976), Las Vegar, Calif.

299. D.F. Othmer and R. Nowak, TiO_2 and Ti metal through the chlorination of ilmenite, *Chem. Eng. Progr.*, **69** (6) (1973), 113.

300. K. Okabe and T. Homada, *Kagaku Kogaku*, **41** (1977), 569.

301. K.A. Schowalter and N.S. Boodman, The clean coke process for metallurgical coke, *Chem. Eng. Progr.*, **70** (6) (1974), 76.

302. H. Seko, et al, Regeneration of coked spent catalyst in fluidized bed, *Kagaku Kogaku Ronbunshu*, **2** (1976), 176.

R. Solid Waste Peocessing

303. K. Arai, et al, Disposal of scrap tires by stirred fluidized beds, *Kagaku Kogaku*, **38** (1974), 385.

304. M. Ichikawa and H. Ando, *J. Japan Petral. Inst.*, **18** (1975), 559.

305. Y. Kawamura, et al, *Kagaku Kogaku*, **38** (1974), 6.

306. Y.H. Kiang, Liquid waste disposal system, *Chem. Eng. Progr.*, **72** (1) (1976), 71.

307. D.L. Klass and S. Ghosh, Fuel gas from organic wastes, *Chemtech*, No **11** (1973), 689.

308. A.D. McIntyre and M.M. Papic, Pyrolysis of municipal solid waste, *Can. J. Chem. Eng.*, **52** (1974), 263.

309. S. Mitsui, et al, Fluidization Technology, vol 2 (1976), pp.561.

310. L.J. Ricci, *Chem. Eng.* **81** (5) (1974), 58.

311. K. Saeki, *J. Japan Petrol. Inst.*, **17** (1974), 652.

312. H. Sinn, *Chemie-Ing-Techn.*, **46** (1974), 579.

313. K. Tamai and A. Fukao, *Chem. Eng.*, **19** (2) (1974), 35.

314. R. Tolman, Int. Conf. on conversion of Reuse to Energy, Montreaux (1975), pp337.

S. Liquid Fluidized Bed

S-1. Miscellaneous

315. V.K. Bhatia, et al, Effect of solids wettability of expansion of gas-liquid fluidized beds, *IEC Process Des. Dev.*, **11** (1972), 151.

316. J.P. Couderc, et al, Transfert de matiere par diffusion en fluidization liquide, *Chem. Eng. Sci*, **27** (1972), 11.

317. P. Dakshinamurty, et al, Bed porosity in gas-liquid fluidization, *IEC Process Des. Dev.*, **11** (1972), 318.

318. S. Damronglerd and H. Angalino, Mass transfer in particulate fluidization, *Trans. Instn Chem. Engrs*, **53** (1975), 175.

319. R.C. Darton and D. Harrison, The rise of single gas bubble in liquid fluidized beds, *ibid*, **52** (1974), 301.

320. A.S. Hercules and C.R. Phillips, Elutriation from two-species liquid-fluidized beds,

IEC Process Des. Dev., **12** (1973), 182.
321. R. Ito, et al, Mass transfer at the wall of liquid fluidized beds, *Kagaku Kogaku*, **37** (1973), 497.
322. P.R. Krishnaswamy and L.W. Shemilt, Correlations for axial mixing in liquid-fluidized beds, *Can. J. Chem. Eng.*, **50** (1972), 419.
323. P.R. Krishnaswamy and L.W. shemilt, Frequency response in liquid fluidized system (I), *ibid*, **51** (1973), 680.
324. C. Laguerie and H. Angelino, A few comments on particle to liquid mass transfer in fluidized bed, *Chem. Eng. Sci.*, **30** (1975), 1525.
325. B.A.J. Latif and J.F. Richardson, Circulation patterns and velocity distributions for particles in a liquid fluidized bed, *Chem. Eng. Sci.*, **27** (1972), 1933.
326. F. Martinola, *Chem. Engrs*, No. **281** (1) (1974), 25.
327. S.C. Mehta and L.W. Shemilt, Frequency response of liquid fluidized systems (II), *Can. J. Chem. Eng.*, **54** (1976), 43.
328. P. Mishra, et al, Momentum transfer to Newtonian and non-Newtonian fluids flowing through packed and fluidized beds, *Chem. Eng. Sci.*, **30** (1975), 397.
329. C. Oloman and A. Watkinson, The electroreduction of oxygen to hydrogen peroxide on fluidized cathodes, *Can. J. Chem. Eng.*, **53** (1975), 268.
330. B.K. O'Neill, et al, The hydrodynamics of gas-liquid contacting in towers with fluidized packings, *ibid*, **50** (1972), 595.
331. K. Ragunathan and K.S. Raju, Eddy thermal diffusivity in liquid-fluidized beds, *IEC Process Des. Dev.*, **15** (1976), 82.
332. K. Ramanurthy and K. Subbaraju, Bed expansion characteristics of annular liquid-fluidized beds, *ibid*, **12** (1973), 184.
333. P.N. Rowe, Paticle-to-liquid mass transfer in fluidized beds, *Chem. Eng. Sci.*, **30** (1975), 7.
334. T. Shirai, *Kagaku Kogaku*, **38** (1974), 19.
335. M.J. Slater, Continuous ion exchange in fluidized beds, *Can. J. Chem. Eng.*, **52** (1974), 43.
336. A. Storck and F. vergnes, *Powder Technol.*, **12** (1975), 209.
337. P.C. Upson and D.L. Pyle, The behaviour of liquid fluidized beds following stepwise changes in flow rate, *Chem. Eng. Sci.*, **29** (1974), 71.
338. B.G. Verbitskii and I.A. Vakhrushev, Ascent velocity of single gas bubble in a liquid-fluidized bed, *Int. Chem. Eng.*, **15** (1975), 277.
339. C.Y. Wen and L.S. Fan, Axial dispersion of non-Newtonian liquids in fluidized bed, *Chem. Eng. Sci.*, **28** (1973), 1768.
340. C.Y. Wen and L.S. Fan, Some remarks on the correlation of bed expansion in liquid-solid fluidized beds, *IEC Process Des. Dev.*, **13** (1974), 194.
341. C.Y. Wen and L.S. Fan, A comparison of recent axial dispersion correlations in liquid-solid fluidized beds, *Can. J. Chem. Eng.*, **52** (1974), 673.
342. N. Yutani and N. Ototake, Mechanism of solids entrainment from the dense phase in liquid-salid fluidized beds, *Kagaku Kogaku Ronbunshu*, **2** (1976), 121.

S-2. Fluidized Bed Electrode

343. D.N. Bennion and J. Newman, Electrochemical removal of copper ions from very dilute solutions, *J. App. Electrochem.*, **2** (1972), 113.
344. D.C. Carbin and D.R. Gabe, Electrodeposition from a fluidized bed electrolyte,

mass transport correlation, *Electrochimica Acta*, **19** (1974), 645.

345. F. Coeuret and A. Gaunand, Study of the effectiveness of fixed flow-through electrodes, *J. App. Electrochem.*, **6** (1976), 417.

346. F. Coeuret and P. Le Gloff, L'Eectrode poreuse percolante(Ⅱ), *Electrochim. Acta*, **21** (1976), 195.

347. D. S. Flett, The fluidized-bed electrode in extractive metallurgy, *Chem. and Ind.*, **16** (1972), 983.

348. M. G. Fouad and G. H. Sedahmed, Mass transfer at gas evolving screen elecirodes, *Electrochem. Acta*, **20** (1975), 615.

349. S. Germain and F. Goodridge, Copper deposition in a fluidized bed cell, *ibid*, **22** (1976), 545.

350. F. Goodridge, Some recent developments of monopolar and bipolar fluidized bed electrodes, *ibid*, **22** (1977), 929.

351. F. Goodrige and A. R. wright, Performance studies on a bipolar fluidized bed electrode, *ibid*, **22** (1977), 1087.

352. F. Goodridge and C. J. vance, The electrowinning of Zinc using a circulating bed electrode, *ibid*, **22** (1977), 1073.

353. J. N. Hiddleston and A. F. Douglas, Current-potential relationships and potential distribution in fluidized bed electrodes, *ibid*, **15** (1970), 431.

354. D. Hutin and F. Coeuret, Experimental study of copper deposition in a fluidized bed electrode, *J.* App. Electrochem., **7** (1 977), 463.

355. L. J. J. Janssen, On oxygen reduction at a fluidized bed electrode, *Electrochem. Acta*, **16** (1971), 151.

356. A. T. Kuhn and W. Houghton, Antimony removal from dilute solutions using a restrained bed electrochemical reactor, *J. App. Electrochem.*, **4** (1974), 69.

357. D. J. Pickett, An approximate design relationship for a fluized bed electrode under conditions of mass transfer control, *ibid*, **5** (1975), 101.

358. J. W. Smith and D. H. King, Electrochemical wall mass transfer in liquid particulate systems, *Can. J. Chem. Eng.*, **53** (1975), 41.

359. A. A. wragg, Application of the limiting current technique in chemical engineering, *Chem. Engr.*, No1 (1977), 39.

T. Three Phase Fluidization

360. C. G. J. Baker, S. D. Kim and M. A. Bergougnou, Wake chracteristics of three-phase fluidized beds, *Powder Technol.*, **18** (1977), 201.

361. P. N. Bruce and Revel-chion, Bed porosity in three phase fluidization, *ibid*, **10** (1974), 243.

362. R. C. Darton and D. Harrison, Gas and liquid holdup in three-phase fluidization, *Chem. Eng. Sci.*, **30** (1975), 581.

363. H. K. Hernriksen and K. Ostergaard, On the mechanism of break-up of large bubble in liquids and three-phase fluidized beds, *ibid*, **29** (1974), 626.

364. H. K. Henriksen and K. Ostergaard, Phase holdup characteristics of three phase fluidized beds, *Chem. Eng. J.* **7** (1974), 141.

365. S. D. Kim and M. A. Bergougnou, Bubble characteristics in shree-phase fluidized bed,

366. S. D. Kim, et al, Bubble characteristics in three-phase fluidized bed, *Chem. Eng. Sci.*, **32** (1977), 1299.

367. I. M. Razumov, et al, The structure of three phase fluidized beds, *Int. Chem. Eng.*, **13** (1973), 57.

168. M. Wozniak and K. Ostergaard, An investigation of mass transfer in a counter-

current three-phase fluidized bed, *Chem. Eng. Sci.*, **28** (1973), 167.

U. Measuring Methods

369. S. M. Csicsery, et al, Catalyst and gas samples for fluid catalytic creaker regenerator, *IEC Process Des. Dev.*, **14** (1975), 93.

370. W. Fuchs and P. M. Yavorsky, New method for measuring bed levels, *Chem. Eng.*, **81** (6) (1974), 145.

371. M. Yamazaki and T. Miyauchi, Measurement of temp. in bubble and emulsion phases in fluid-bed, *Kagaku Kogaku Ronbunshu*, **3** (1977), 261.

372. M. Yamazaki, et al, A method for measurement of spatial distribution of bubbles in a fluidized bed, *ibid*, **3** (1977), 266.