at the bottom of the dam ring to remove fines on the table (which would otherwise form a dormant layer cushioning the grinding action of the rolls).

The overloading of the separator by more oversize particles could be overcome by installing a double type classifying action - static adjustable vanes followed by a rotating basket, or blade type whizzer, as on the present mills. It is felt that in future higher duties will be imposed on separators and new designs will have to be introduced to keep plant to within reasonable sizes. for example, two separate separators per mill might be more economical.

It was mentioned above that the velocities within the mill plenum above the table should be kept low and an alternative method that has been proposed is as follows: the total air flow through the mill is governed by drying requirements and transport concentrations of the dust/air mixture going out of the mill. The total air flow normally enters through the annular throat, although not all this amount is theoretically required for entrainment of the material off the table. Therefore, if the throat size were to be decreased to prevent reject spillage, and some of the inlet air were by-passed and introduced at a point above the throat, low velocities could still be maintained directly above the table without sacrificing total air flow in the separator and conveying pipes. Figure 8.4 illustrates this point. Also, by installing dampers in the by-pass ducts, the throat velocities would be controlled for either different operational conditions or, say, grinding of denser material to prevent excessive rejection.

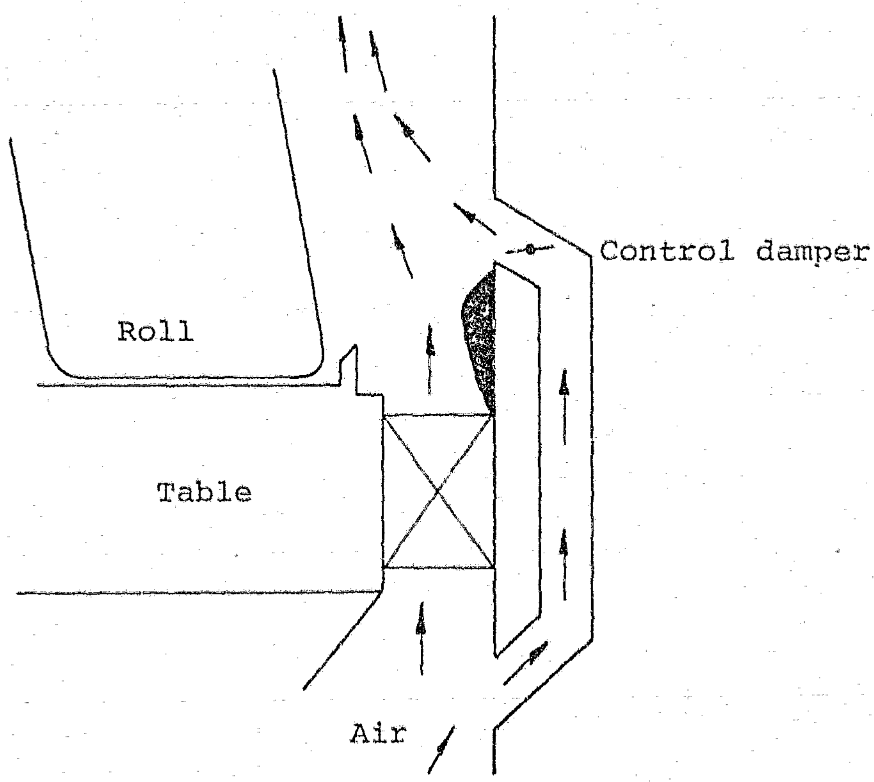


FIGURE 8.4: Proposed Air By-pass System

8.1.3 Materials

The development of wear resistant materials has certainly kept abreast of mill development and future increases in size will not be affected or handicapped by the availability of suitable materials. The temperature of the inlet air (at present about 500°C) could be raised by using special alloys on the mill inlet casing but this is not often economically feasible.

8.2 CONCLUSION

The feasibility of extending the capacity range of vertical spindle mills seems extremely good provided that the problems are realised now by both designer and user so that realistic targets can be set and the necessary design changes implemented in good time. The mills will become larger, the roll type mills will have four, six or even eight rolls - approaching the ball ring roll mill - and drives will be altered so that an economically viable mill is the result.

CHAPTER 9

SUGGESTIONS FOR FUTURE WORK

The field of research into mills and associated parameters is extremely large and much work is being done at present on the development and improvement of existing systems. However, arising out of this study, some desirable avenues of research are as follows:

1) Study of the fluidized bed directly above the throat in relation to various throat geometries, especially with a view to minimising the Coanda effect. The by-pass throat is one possible solution.

2) Development of a system to effect non-combustible grit removal off the mill table. This grit, being denser than the coal, tends to remain on the table longer, giving rise to high wear on rolls and table segments.

3) Study of an arrangement for driving the rolls and not the table. This has been tried on a small scale with promising results and presents definite advantages in larger installations.

4) On-line sampling and flow measurement are still not satisfactory and although results are obtainable, the methods available are tedious.

CHAPTER 10

CONCLUSIONS

10.0 INTRODUCTION

In this Chapter the main conclusions drawn from the various tests will be summarised.

10.1 MILL MODEL TESTS

The 1/6th and 1/8th scale models were tested in a water circuit to visually confirm postulated flow configurations, with the following results:

(i) There was a Coanda effect along the sides of the mill body in the Lopulco model.

(ii) Recirculation takes place in the conical body section and oversize particles have to fall through a high velocity zone to reach the table for further grinding.

(iii) There are dead areas within the body space.

(iv) The separator efficiency could be improved by widening the flow distribution across the radial blades.

(v) Throat deflectors could eliminate to a large extent the Coanda effect as well as decreasing the recirculation behind the rolls (in roll cover).

(vi) The static classifier is preferred from a flow path point of view and ensures more positive oversize return.

(vii) The models were most useful in visually confirming previously observed effects as well as highlighting further problem areas.

10.2 FLUIDIZED BED TESTS

Tests with various materials of differing shapes in air and water as the fluidizing medium highlighted well known phenomena as well as serving as an introduction to the basic background of flow principles. The following conclusions emerged:

(i) The results were reasonably in line with published data although the particle shape factor was found to influence the scatter of results to a greater or lesser degree.

(ii) A slugging frequency to velocity ratio relationship was noted in the air-solid system.

10.3 INDUSTRIAL TESTS

These tests were conducted after the model tests and were performed during commissioning and in the early running stages of full scale mills. Nevertheless, certain operating problems were brought to light which were in some measure solved by the information gleaned from the model results:

(i) The most suitable throat arrangement was found to be associated with an inward flow direction above the throat, with rounded inlet edges to the louvre.

(ii) The bypass cone has proved commercially viable and represents a totally new concept in throat design.

(iii) Temperature gradients recorded within the mill showed a high heat transfer at the throat, indicating low voidage directly above the throat.

(iv) Voidage within the mill plenum and separator was high; appropriate measurements could enable a calculated recirculating load to be obtained.

(v) The separator design at Arnot was poor and the flow paths should be redesigned to prevent wear and impingement resulting from a high value of recirculation.

(vi) The separator sleeve provided a useful fineness adjustment without too high a pressure drop.

(vii) Sampling probes as a permanent installation can be successful if research is undertaken to establish a suitable design.

(viii) Irradiated coal can be used as a tracer for time determination provided it is used immediately, as it has a relatively short half-life.

(ix) Use of the uniformity coefficient and an average particle size simplify parameter assessment.

APPENDIX A

The references are grouped under the following headings:

B - Modelling

C - Combustion

F - Fluidization

G - Grinding

M - Milling

P - P.f. Measurement

T - Pneumatic Transport

W - Wear

MODELLING

B1 ARCHBOLD, M J. A Visual Qualitative Approach to Duct Design for Power Plants. *Combustion*, 34-40, 1958.

B2 BEÉR, J M. The Significance of Modelling. . *J Inst Fuel*, 39 : 466-473, 1965.

B3 GRAY, F A and ROBERTSON, A D. The Investigation of Fluid Flow Problems by Model Techniques. *J Inst Fuel*, 29 : 428-438, 1956.

B4 HIETT, G F. Three Dimensional Probe for Investigation of Flow Patterns. *The Engineer*, 165-170, 1962.

B5 INTERNATIONAL COMBUSTION LTD. The Use of Paint Techniques in the Determination of Air Flows. *International Combustion Ltd*, Internal Report, 1964.

B6 INTERNATIONAL COMBUSTION LTD. An Introduction to the International Combustion Ltd Steam Generation Division Research Laboratories. *International Combustion Ltd*, Brochure, 1965.

B7 LITTLEJOHN, R F and SPENCER, D H T. Radioactive Tracers in Fuel Technology. *J Inst Fuel*, 31 : 160-165, 1958.

B8 MERZKIRCH, W F. Making Flows Visible. *Ind Sci & Tech*, 46-56, 1966.

B9 PATTERSON, R C and ABRAHAMSEN, R F. Flow Modelling of Furnaces and Ducts. *Combustion*, 47-55, 1962.

B10 PRAHL, W H. Simplifying Pressure-Drop Calculations. *Chem Eng*, 139-146, 1965.

B11 RUSHTON, J H. Application of Fluid Mechanics and Similitude to Scale-up Problems. *Chem Eng Prog*, 48, No 1, 33-38, 1952.

B12 *Ibid*, No 2, 95-102, 1952.

B13 SAWYER, R A. Two Dimensional Reattaching Jet Flows including the Effects of Curvature on Entrainment. *J Fluid Mech*, 17 : 481-498, 1963.

B14 STREET, P J and TWAMLEY, C S. A Technique for Flow Visualisation using Chemical Indicator Solutions. *J Sci Instrum*, 44 : 558-559, 1968.

B15 TIETJENS, O G. The Use of Models in Aerodynamics and Hydrodynamics. *Trans ASME*, Report APM-54-22, 225-232, 1933.

B16 WERLÉ, H. Simulation de L'Effet de Sol au Tunnel Hydrodynamique. *La Recherche Aérospatiale*, 95 : 1963.

B17 WERLÉ, H. Méthodes de Visualisation des Écoulements Hydrauliques. *La Houille Blanche*, 5 : 1963.

COMBUSTION

C1 BANDYOPADHYAY, S and BHADURI, D. Effect of Particle Size and Distribution in the Combustion of Coal Dust. *J Inst Fuel*, 44 : 377-380, 1971.

C2 HEDLEY, A B and LEESLEY, M E. Burning Characteristics of Pulverized Coal. *J Inst Fuel*, 38 : 492-500, 1965.

C3 IVANOVA, I P and BABII, V L. A Study of the Burn-Out Mechanism of Coal Particles. *Thermal Eng*, 13(4) : 70-76, 1966.

C4 KOVALEV, A P, KHZMALYAN, D M and VILENSKII, T V. Experimental Study of the Ignition of Pulverized Coal in a Fuel-Air Stream. *Thermal Eng*, 12(9) : 19-24, 1965.

C5 LEESLEY, M E and SIDDALL, R G. The Combustion Rate of a Pulverized Anthracite Dust Cloud of Known Initial Particle Size Distribution. *J Inst Fuel*, 45 : 169-173, 1972.

C6 MINISTRY OF POWER. *The Efficient Use of Fuel*. 2nd Ed. London, HMSO, 1964.

C7 RIEL, W. Measures to obtain Optimum Combustion in a Slag-Tap Furnance of a Pulverized Coal-Fired 100 MW Boiler with Direct Injection (in German). *Mitt V G B*, 105 : 428-431, 1967.

C8 ROSIN, P O. The Mechanism of Combustion of Pulverized Fuel. *J Inst Fuel*, 31 : 346-355, 1958.

FLUIDIZATION

F1 BOURGEOIS, P and GRENIER, P. The Ratio of Terminal Velocity to Minimum Fluidizing Velocity for Spherical Particles. *Can J Chem Eng*, 46 : 825-828, 1968.

F2 ERGUN, S and ORNING, A A. Fluid Flow through Randomly Packed Columns and Fluidized Beds. *Ind & Eng Chem*, 41, No 6, 1179-1184, 1949.

F3 FONG, W W. Fluidization. Final Year Laboratory Report. Mechanical Engineering Department, University of the Witwatersrand, 1963.

F4 HANRATTY, T J and BANDUKWALA, A. Fluidization and Sedimentation of Spherical Particles. *AIChE Journal*, 3, No 2 : 293-296, 1957.

F5 LEVA, M *et al.* Fluidization of an Anthracite Coal. *Ind & Eng Chem*, 41, No 6 : 1206-1212, 1949.

F6 LEVA, M. *Fluidization.* New York, McGraw-Hill, 1959.

F7 OTHMER, D F and ZENZ, . *Fluidization and Fluid-Particle Systems.* New York, Reinhold, 1960.

F8 PERRY, J H. *Chemical Engineers' Handbook.* 4th Ed, Tokyo, McGraw-Hill, Kogakusha, 1963.

F9 RICHARDSON, J F and ZAKI, W N. Sedimentation and Fluidization : Part 1. *Trans Inst Chem Eng*, 32 : 35-53, 1954.

F10 WILHELM, R H. Fluidization of Masses of Particles. *Proc 2nd Midwestern Conf on Fluid Mech*, 379-387, 1952.

F11 WINTER, O. Density and Pressure Fluctuations in Gas Fluidized Beds. *AIChE Journal*, 426-434, 1968.

GRINDING

G1 ARBITER, N and HARRIS, C C. Particle Size Distribution/Time Relationship in Comminution. *Brit Chem Eng*, 10 : 240-247, 1965.

G2 AUSTIN, L G and KLIMPEL, R. The Theory of Grinding Operations. *Ind Eng Chem*, 56, No 11, 13-29, 1964.

G3 BENNETT, J C. Broken Coal. *J Inst Fuel*, 10 : 22-39, 1936.

G4 BOND, F C. New Ideas Clarify Grinding Principles. *Chem Eng*, 103-108, 1962.

G5 BOND, F C. The Third Theory of Comminution. *Trans AIME*, 193 : 484-494, 1952.

G6 BOND, F C. Crushing and Grinding Calculations. Allis-Charmers Industrial Press Dept, 1955.

G7 BOWN, R W. Energy Distribution in Pulverizing. *Trans Ins Min Metall, Section C*, 75 : C173-C180, 1966.

G8 BROADBENT, S R and CALLCOTT, T G. Coal Breakage Processes. I : A New Analysis of Coal Breakage Processes. *J Inst Fuel*, 29 : 524-439, 1956.

G9 BROADBENT, S R and CALLCOTT, T G. Coal Breakage Processes. III : The Analysis of a Coal Transport System. *J Inst Fuel*, 30 : 13-17, 1957.

G10 BROADBENT, S R and CALLCOTT, T G. Coal Breakage Processes. IV : An Exploratory Analysis of the Cone Mill in Open-Circuit Grinding. *J Inst Fuel*, 30 : 18-21, 1957.

G11 BROADBENT, S R and CALLCOTT, T G. Coal Breakage Processes. V : Analysis of Closed-Circuit Grinding. *J Inst Fuel*, 30 : 21-25, 1957.

G12 BROWN, R L and HURLEY, T F. Some Experiences of Pulverizing Coal. *5th World Power Conf, Vienna.* 1297-1311, 1956.

G13 CALLCOTT, T G. Coal Grindability - A Standardised Procedure for the Determination of Coal Grindability and a Survey of the Grindabilities of British Coals. *J Inst Fuel*, 29 : 207-217, 1956.

G14 CALLCOTT, T G. Coal Grindability. II : Effect of Sample Preparation in the Hardgrove Test. *J Inst Fuel*, 30 : 466-471, 1957.

G15 CALLCOTT, T G. Size Distribution and Single Particle Breakage. *BHP Tech Bull*, 26 : 26-30, 1966.

G16 CALLCOTT, T G. Matrix Algebra and a Summary of Conventions relating to Particular Materials. *Trans Ins Min Metall, Section C*, 76 : C60-C65, 1967.

G17 GAUDIN, A M and MELOY, T P. Model and a Comminution Distribution Equation for Single Fracture. *Trans Am Inst Min Engrs*, 223 : 40-43, 1962.

G17A GARDNER, R P and AUSTIN, L G. *A Radioactive Tracer Technique for the Determination of Breakage Functions.* 1st European Symposium on Size Reduction, Weinheim, Verlag Chemie, 1962, lV.

G18 GAUDIN, A M and MELOY, T P. Model and a Comminution Distribution Equation for Repeated Fracture. *Trans Am Inst Min Engrs*, 223 : 43-50, 1962.

G19 GREENWOOD, J and HIORNS, F J. *A Comparison of Individual and Collective Breakage of Particle Assemblies.* Paper A5 2nd European Symposium on Size Reduction, Weinheim, Verlag Chemie, 1966, 2V.

G20 EPSTEIN, B. Logarithemico - Normal Distribution in Breakage of Solids. *Ind & Eng Chem*, 40 : No 12, 2289-2291, 1948.

G21 KAPUR, P C. The Energy - Size Reduction Relationship in Comminution of Solids. *Chem Eng Sci*, 26 : 11-16, 1971.

G22 LITTLEJOHN, R F. Mineral Matter and Ash Distribution in "As-fired" Samples of Pulverized Fuels. *J Inst Fuel*, 39 : 59-67, 1966.

G23 MELOY, T P. A Three-Dimensional Derivation of the Gaudin Size Distribution Equation. *Trans Am Inst Min Engrs*, 226 : 447-448, 1963.

G24 PIRET, E L. Fundamental Aspects of Grinding. *Chem Eng Prog*, 56-63, 1953.

MILLING

M1 BARTON, F M. Operating Experience with New Pulverizer Application at Thunder Bay Generating Station. *Proc Am Power Conf*, 26 : 310-317, 1964.

M2 BEKE, B. *Principles of Comminution*. Budapest, Akademiai Kiado, 1964.

M3 CALLCOTT, T G. Pulverizing Coals. *Proc Australian Inst Min Metall*, 183 : 43-76, 1957.

M4 EICKE, G. The Control Behaviour of Coal Pulverizing Mills.(in German). *Brennst-Wärme Kraft*, 18, No 2, 55-60, 1966.

M5 ERICKSON, H W. Types of Grinding Mills and when to use them. *Chem Eng Prog*, 63-68, 1953.

M6 FITTON, A and JACKSON, D. Some Experiences of Coal Grinding Plant Tests on a Ring-Ball Mill and a Tube Mill. *J Inst Fuel*, 32 : 520-529, 1959.

M7 FITTON, A, HUGHES, T H and HURLEY, T F. The Grindability of British Coals - A Laboratory Examination. *J Inst Fuel*, 30 : 54-65, 1957.

M8 HAMILTON, T B and VAUGHAN, P H. Air Systems for Pulverized Coal Firing. *Proc Am Power Conf*, 28 : 645-651, 1966.

M9 HENNECKE, H. Bituminous Coal Pulverizing for Steam Generators; Assessment and Selection of Mills. *The Monthly Tech Bull of International Combustion Limited*, 15 : 326-344, 1961.

M10 HIORNS, F J and REED, L E. The Performance of an Air-Swept Tube Mill. *J Inst Fuel*, 31 : 383-392, 1958.

M11 HIORNS, F J. *Energy Conversion in Milling*. Paper A6, 2nd European Symposium on Size Reduction. Weinheim : Verlag Chemie, 1966, 2V.

M12 INTERNATIONAL COMBUSTION LTD. Pressure Drop Measurements through Mill Base Models. Report A10 : 1965.

M13 INTERNATIONAL COMBUSTION LTD. Investigation of Pressure Drops and Re-entrainment of Oversize Particles in a Whizzer Separacor Model. Report A2 : 1963.

M14 INTERNATIONAL COMBUSTION LTD. Investigation of the Flow of Coal over a Mill Table, using a Scale Model. Report A6 : 1964.

M15 INTERNATIONAL COMBUSTION AFRICA LTD. Milling Plant Investigations: Camden Power Station. *International Combustion Africa Limited.* Report T69/2, 1969.

M16 JOINT COMMITTEE OF THE FUEL RESEARCH BOARD AND THE BRITISH COAL UTILISATION RESEARCH ASSOCIATION. Interim Report on Pulverizer Tests. *J Inst Fuel*, 28 : 30-36, 1955.

M17 JOINT COMMITTEE OF THE FUEL RESEARCH BOARD AND THE BRITISH COAL UTILISATION RESEARCH ASSOCIATION. The Grinding of Coal in a Ring Ball Mill. *J Inst Fuel*, 30 : 269-276, 1957.

M18 KEYSSELITZ, VON G. Steinkohlenmuhlen fur Große Dampferseuger. *Mitt V G B*, 110 : 329-339, 1967.

M19 KIRKMAN, D. Report on the Desirability of Nominal Rejects from Loesche LM18/1340D Mills at Arnot Power Station. *International Combustion Africa Ltd*, Internal Report, 4 pp, 1972.

M20 KISELEV, P I and KONDRAT'EVA, L N. Improving the Pulverizing Process in Medium-Speed Ring-Roll Mills. *Thermal Eng*, 17(2) : 54-57, 1970.

M21 KRÜGER, J I de W. An Investigation of the Influencing Milling Cost Parameters in Escom Power Stations. *International Combustion Africa Ltd*, Report, 1974.

M22 McKENZIE, E C *et al.* Recent Advances in Ring and Ball Pulverizers. Babcock and Wilcox Publication No. 1884/1.

M23 MESSERSCHMIDT, L J. Second Report on Ball Charge Tests - Komati 4B Mill. ESCOM Report, 5 pp, 1970.

M24 MESSERSCHMIDT, L J. The Calibration of Airswept, Slow Speed, Vertical Spindle Coal Mills with the Object of obtaining Optimum Performance. *SAIMechE Symposium on Milling*, Johannesburg, 1971.

M25 MOTEK, H. Praxis der Hartzerkleinrung. *Aufbereitungs Technik*, 4 : 207-217, 1973.

M26 NORTH, R. Fine Crushing and Grinding. *The Quarry Manager's Journal: Inst of Quarrying Trans*, 1969.

M27 NORTH, R. Fine Grinding. *The Quarry Manager's Journal*, 7 pp, 1962.

M28 ROSE, H E, EVANS, D E and BLUNT, G D. The Dynamics of the Ball Mill: Parts 1-3. *Proc Inst Mech Engrs*, 170 No 23 : 773-811, 1956.

M29 SCHNEIDER, G. M P S Type Roller Mill for Grinding Bituminous Coal (in German). *Aufbereitungs Technik*, 9 : 537-549, 1971.

M30 SCHÖNING, W. Roller Mills. A Contribution to the Assessment and Selection of Coal Pulverizing Mills. *The Monthly Tech Bull of International Combustion Ltd*, 15 : 250-258, 1961.

M31 QUESNEL, G. La chauffe au charbon pulvérisé avec les broyeurs Bowl-Mill. *Combustion du Chauffage Industriel Moderne*, 128 : 1967.

M32 WESTHOFF, G. Operational Experience with Roller Ring Mills. *The Monthly Tech Bull of International Combustion Ltd*, 18 : 154-166, 1964.

M33 COMBUSTION ENGINEERING. Mill Catalogue.

M34 LOESCHE K G. Mill Catalogue.

M35 Private Communications - Loesche K G.

M36 Private Communications - International Combustion.

P.F. MEASUREMENT

P1 BOALS, R E. Establish Limits for Pulverizer Fineness Tests. *Power*, 214-215, 1961.

P2 CENTRAL ELECTRICITY GENERATING BOARD. The Effect of Dust Burden on Pitot-Static Readings. *CEGB*, Report No 602, 1965.

P3 CENTRAL ELECTRICITY RESEARCH LABORATORIES. Use of the Annular Venturi for Mass Flow Measurements on Airborne Pulverized Fuel. Paper presented to IEE 1968.

P4 CONNOR, R and HARDWICK, W H. The Use of Radioactivity in Particle Size Determination. *Ind Chemist*, 427-433, 1960.

P5 GRABENHORST, U. Measurements on Pulverized Coal Ducts (in German). *Mitt V G B*, 105 : 431-433, 1966.

P6 HUBEL VON, E. Measurement of Pulverized Coal Flow in Pipe Lines. *The Monthly Tech Bull of International Combustion Ltd*, 14 : 394-408, 1960.

P7 INTERNATIONAL COMBUSTION AFRICA LTD. Report on P.F. and P.A. Distribution Investigation. *International Combustion Africa Limited*, Internal Report, 1968.

P8 JUNG, R. Problems of Pulverized Coal and Air Distribution in Pulverized Coal Firing Burners. *The Monthly Tech Bull of International Combustion Ltd*, 14 : 42-58, 1960.

P9 KOCH, U. Pulverized Coal Measurements on a Roller Mill (in German). *Mitt V G B*, 105, 424-427, 1966.

P10 NORTH, R. Particle Size Classification. *International Combustion Ltd*, Reprint, 29 pp.

P11 PARKINSON, M J. The Measurement of Pulverized Coal Mass Flow in Ducts. *B C U R A Info Circ*, No 327, 1967.

P12 RADO, L. The Concentration and Fineness of Grinding of Pulverized Coal in Ducts from Mills, especially their Change with Time (in German). *Mitt V G B*, 105 : 418-424, 1966.

P13 ROMANOV, V A and NEMTSEV, Z F. A Method for Selecting Optimum Fineness of P.F. *Thermal Eng*, 11 : No 9, 34-40, 1964.

P14 ROSIN, P and RAMMLER, E. The Laws Governing the Fineness of Powdered Coal. *J Inst Fuel*, 7 : 29-36, 1933.

P15 SAUNDERS, P R and YOUNG, D H. Pulverized Fuel Flow Measurement by a Venturi - Phase One. CERL Internal Report.

P16 SCARLETT, B. Particle Size Analysis. *Chem & Proc Eng*, 197-201, 1965.

P17 SNOWSILL, W L. Further Developments of the CERL Pulverized Fuel Riffle. CERL Report No RD/L/R 1513, 1968.

P18 SNOWSILL, W L. Development of a New Form of Pulverized Fuel Riffle. CERL Report No RD/L/N 120/63, 1963.

P19 SNOWSILL, W L. The Development of a Rotary P.F. Sampler. CERL Report No RD/L/N 82/66, 1966.

P20 STONNER, A *et al.* Measurement of Coal Dust Concentration in Pipelines Using Radioactive Isotopes. *Combustion,* 26-29, 1973.

P21 TEWES, L. Determination of the Amount of Pulverized Coal in Ducts. *The Monthly Tech Bull of International Combustion Ltd,* 19 : 42-50, 1965.

PNEUMATIC TRANSPORT

T1 CAIRNS, R C, LAWTHER, K R and TURNER, K S. Flow Characteristics of Dilute Small Particle Suspensions. *Brit Chem Eng,* 5 : 849-856, 1960.

T2 KANE, L F and SPENCER, J D. Pneumatic Coal Transport: Difficult but Promising. *Power Eng,* 58-59, 1966.

T3 LEMPP, M. The Conditions of Flow of Gas-Solid Mixtures in Branchings of Pneumatic Conveying Plants. *Aufbereitungs Technik,* 7 : 81-91, 1966.

T4 MOLYNEUX, F. Pneumatic Conveying Fundamentals. *Fluid Handling,* 152-154, 1961.

T5 *Ibid,* 192-194.

T6 PATTERSON, R C. Pulverized Coal Transport through Pipes. *Combustion,* 47-57, 1958.

T7 ROSE, H E and DUCKWORTH, R A. Transport of Solid Particles in Liquids and Gases. *The Engineer,* 392-396, 1969.

T8 *Ibid*, 430-433.

T9 *Ibid*, 478-483.

T10 VAN DER LINGEN, T W and KOPPE, R. Moving Granular Materials by Air Line. *Engineering*, 349-351, 1963.

WEAR

W1 COOLING, D R. Investigation of Wear in Coal Pulverizers. Part 2: Considerations of the Minerals present in Coal in relation to Pulverizer Wear. *B C U R A Info Circ*, No 296, 1964.

W2 COOLING, D R and PARISH, B M. Investigations of Wear in Coal Pulverizers. Part 5: Effects on Wear Rates of Shale, Quartz and Muscovite Additions to a Coal Feed. *B C U R A Infor Circ*, No 310, 1964.

W3 DU TOIT, P and BONAPACE, A C. Determination of the Abrasiveness of Coal with the Apparatus of Yancey, Geer and Price. *Coal, Gold and Base Min of SA*, 49-57, Nov 1973.

W4 *Ibid*, 36-42, Dec 1973.

W5 GIBBINGS, J C. Dimensional Analysis of Wear by Particle Impact in Fluid Flows. *J Mech Eng Sci*, 13, No 4 : 234-236, 1971.

W6 GREENWOOD, J. Investigation of Methods of Labelling Coal Particles with Tritium for Breakage Studies. *B C U R A Info Circ*, No 286, 1964.

W7 HIORNS, F J and PARISH, B M. Investigations of the Wear of Coal Pulverizers. Part 1: General Considerations and Description of a Laboratory Method. *J Inst Fuel*, 39 : 126-133, 1966.

W8 INTERNATIONAL COMBUSTION LTD. Determination of a Wear Ratio between an LM16 Model Mill, Commercial Size LM16/3 Mills and Laboratory Scale Mills and the effect of Alpha Quartz content of Dry Coal on Wear of these Mills. Report, 1968.

W9 PARISH, B M. Investigation of Wear in Coal Pulverizers. Part 2: An Assessment of the Abrasive Properties of Low Ash Coals. *J Inst Fuel*, 40 : 76-81, 1967.

W10 PARISH, B M and BEAMAN, A L. Investigations of Wear in Coal Pulverizers. Part 6: The Relation between Abrasion Index and Wear Rates measured on a Roll Crusher Apparatus. *B C U R A Info Circ*, No 311, 1964.

W11 Private communication from Mr L J Messerschmidt.

APPENDIX B

Associated laboratory and sampling equipment

APPENDIX B

ASSOCIATED EQUIPMENT

B.1 HARDGROVE MACHINE

This machine is a small laboratory ring-ball mill used to grind material samples. It consists of eight spherical balls of 25 mm diameter rolling between a lower stationary ring and rotating loaded upper ring (Figure B.1). An air-dried 50 g pre-sized sample is introduced into the mill and ground for 60 revolutions of the mill with the upper grinding ring loaded to 2.96 N. The Hardgrove Index for coal is then determined by the equation

Hardgrove Index: $H_i = 13 + 6.93\ D(x)$

where D(x) is the mass in g of ground sample passing through a 200 mesh sieve.

It follows that the lower the Index, the more difficult the material is to grind, and this basis is used to size and compare grinding plant requirements for a particular application.

B.2 ABRASIVE INDEX*

This Index is used to specify the abrasiveness of the material being ground. A pre-sized and weighed sample is put in a Yancey, Geer and Price machine which rotates weighed steel paddles in the sample at a set speed for a set number of revolutions. After the test, the paddles

*The test is fully described in Trans AIMME, Vol 190 (1951)

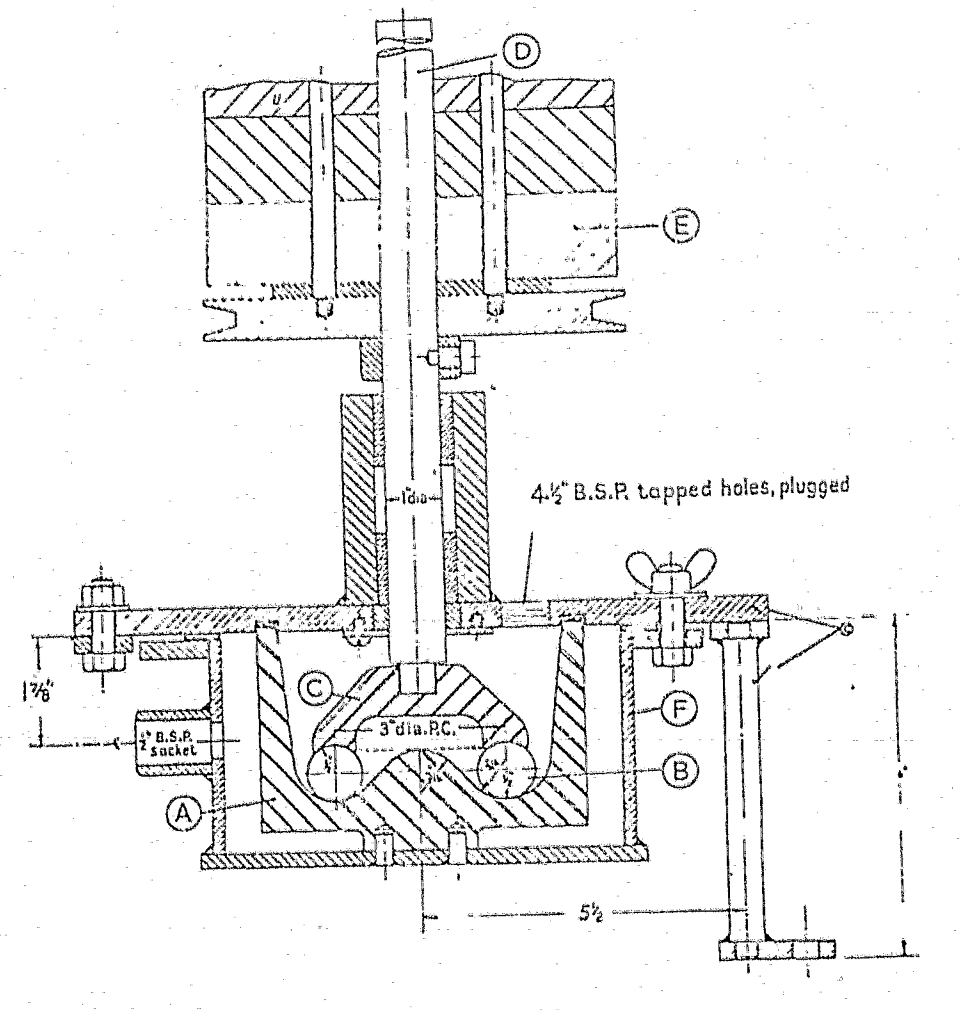


FIGURE B1: Hardgrove machine
A, Grinding bowl. B, Ball bearings. C, Upper grinding ring. D, Driving spindle. E, Steel blanks. F, Outer casing. G, Stand.

are washed, dried and re-weighed. The mass loss is a measure of the abrasive qualities of the material and the higher the Index, the more abrasive the material.

B.3 ROTAP SIEVING MACHINE

This machine enables a sample of ground material to be sieved and graded through various size ranges simultaneously. The required sieves are stacked on top of one another with the largest sieve apertures at the top and a collecting pan at the bottom. A lid is provided for the top sieve. A weighed sample - approximately 100 g - is introduced into the top sieve, and the machine is then run for 5 to 10 min.

The sieving action is achieved by moving the stack of sieves in a cyclic horizontal motion and tapping the top of the stack by means of a lifting and falling lever arm, thereby keeping the material in continuous motion, and preventing 'blinding' of the apertures. The sieves are then individually weighed to determine the residue material on each size range.

B.4 GRINDABILITY INDEX

A 203 mm diameter by 203 mm long ball mill is used to determine the Grindability Index. The ball charge consists of 100 steel balls of 25 mm diameter, with three equispaced lifter bars to promote the tumbling action.

An air dried 500 g pre-sized sample is introduced into the mill, which is then rotated at 40 r/min. A trip counter records the revolutions. The coal is ground in stages to limit each stage to about 10% of the sample to pass 200 mesh. Only the oversize is returned to the mill for further grinding after each stage.

The Index is defined as

$$\text{Grindability Index} = \frac{50\ 000}{\text{No of revolutions}}$$

where the revolutions are taken at 80% sample product minus 200 mesh.

Linear correlation with the Hardgrove Index has been found experimentally.

B.5 ISOKINETIC SAMPLER (Figure B.2)

The isokinetic sampler was developed for use mainly in power stations for the sampling of pulverized fuel. The principle employed is that the sample is withdrawn from the p.f. piping at the same velocity as the local air-coal velocity in the pipe, thereby not disturbing the flow pattern within the pipe. The measurement of local velocity is made by means of a combined Pitot/sampling probe which has an air purge to keep it clean whilst moving from point to point within the dust stream.

To withdraw the sample, the probe is positioned at the selected points within the pipe, these being chosen at the centres of equal areas, so that a completely representative sample is obtained - increasing in accuracy with the number of sampling points selected.

Having established (prior to the sampling) the velocity at each of these selected points, the withdrawal velocity is adjusted during sampling to match this velocity. A later probe development eliminates the velocity traverse and by balancing static legs, isokinetic sampling is achieved.

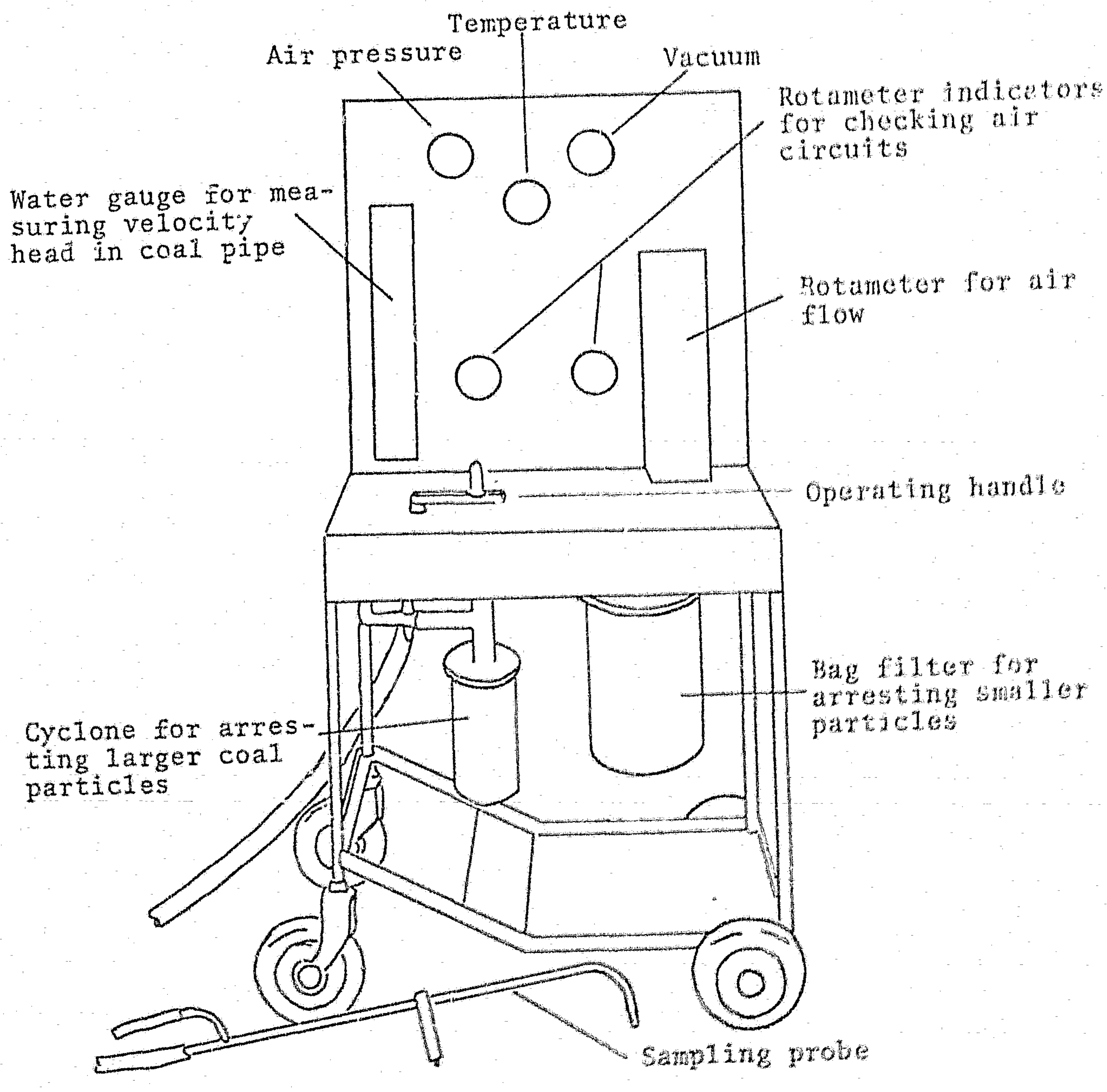
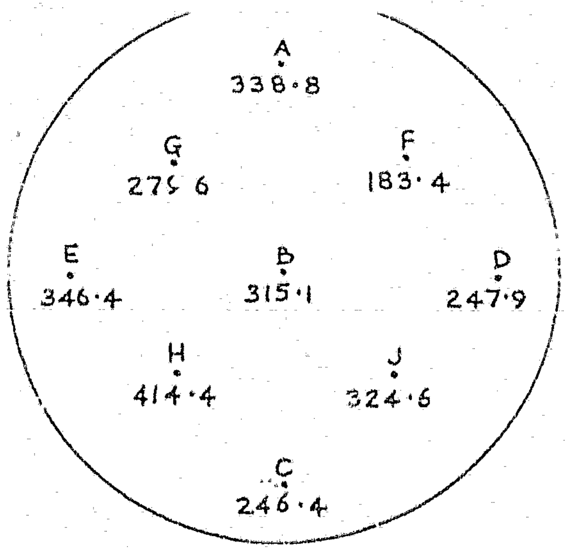
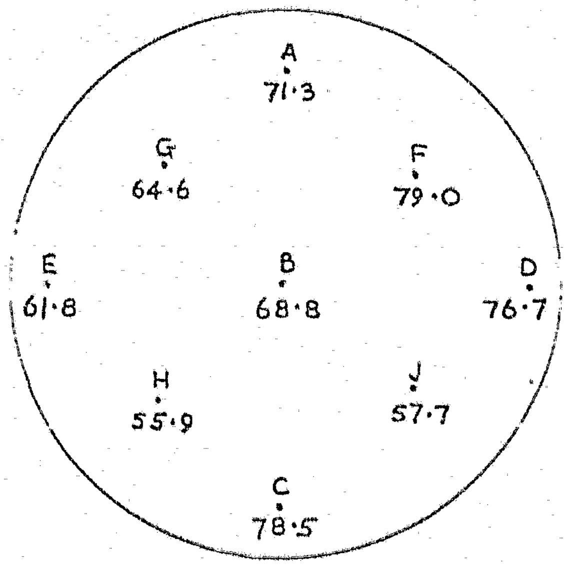


FIGURE B2: Isokinetic sampler



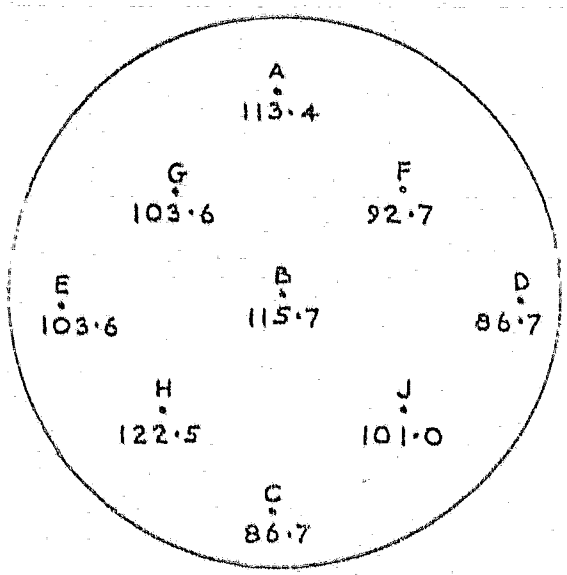
MASS DISTRIBUTION IN COAL PIPE

Figures give mass of coal withdrawn in 3 min intervals



PERCENTAGE THROUGH 200 B.S. SIEVE

Weighted average for all positions = 66.78%



VELOCITY DISTRIBUTION IN COAL PIPE

Figures give velocity of coal-air mixture in ft/s

FIGURE B3: Typical conditions in a vertical coal pipe (from P12)

The withdrawn coal/air mixture is passed firstly through a cyclone which removes the majority of the dust, and then through a dust filter-bag. The cleaned air is then withdrawn through a rotameter to meter the flow and an air ejector operated by compressed air. The probe is connected to these portable desk mounted devices by means of clear plastic hose.

Figure B.3 shows a typical velocity distribution within a p.f. pipe. It is apparent how wide a scatter occurs.

B.6 I.C.L. PROBE (Figure B4)

For ease of sampling and spot checks, this probe is used extensively although its accuracy is not as high as for the isokinetic probe. It consists of a 25 mm bore pipe inserted into the dust stream at 45° to the direction of flow, drawing off a sample into a filter paper bag by pressure differential between pipe and atmosphere. The probe is designed to suit the pipe diameter, and is split along its length within the pipe, thus presenting an elongated concave section to the dust stream.

Usually two diameters per pipe at 90° to each other are sampled and the sample combined for sieving.

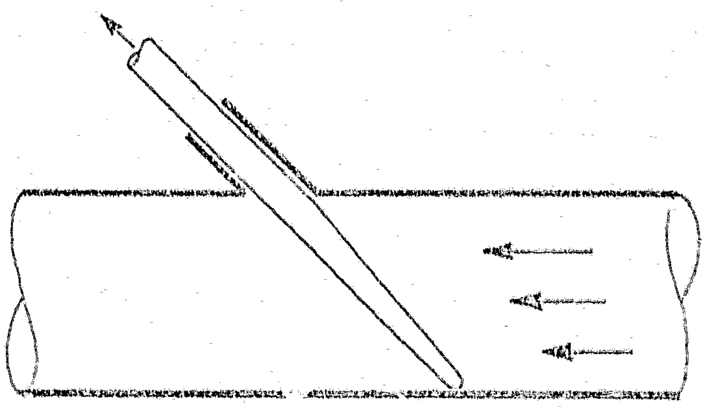


FIGURE B4: I.C.L. Sampling Probe

A P P E N D I X   C

Drawing of orifice plate and calibration reference curves for the model flow tests

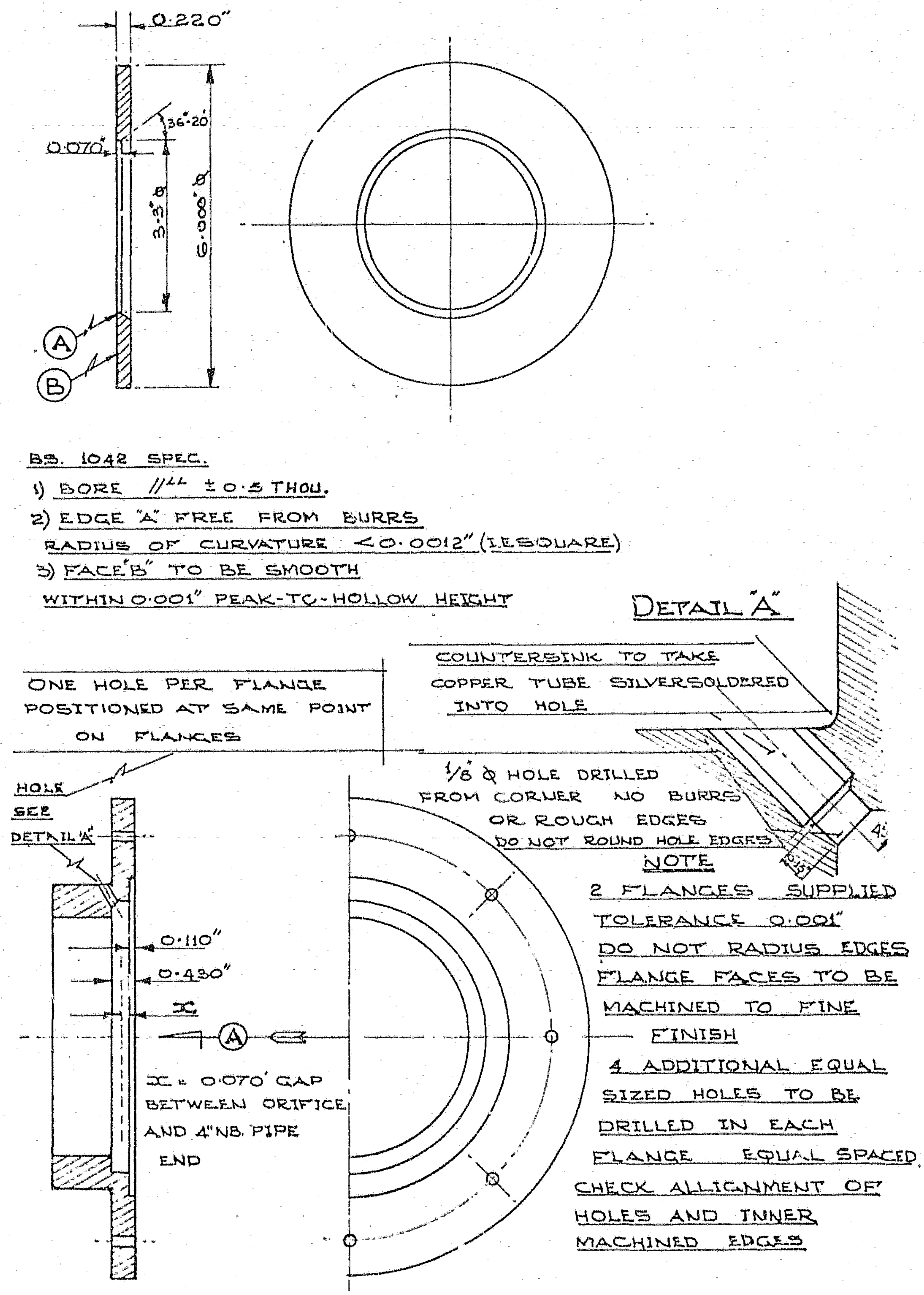


FIGURE C1: Orifice plate and flange for water model circuit

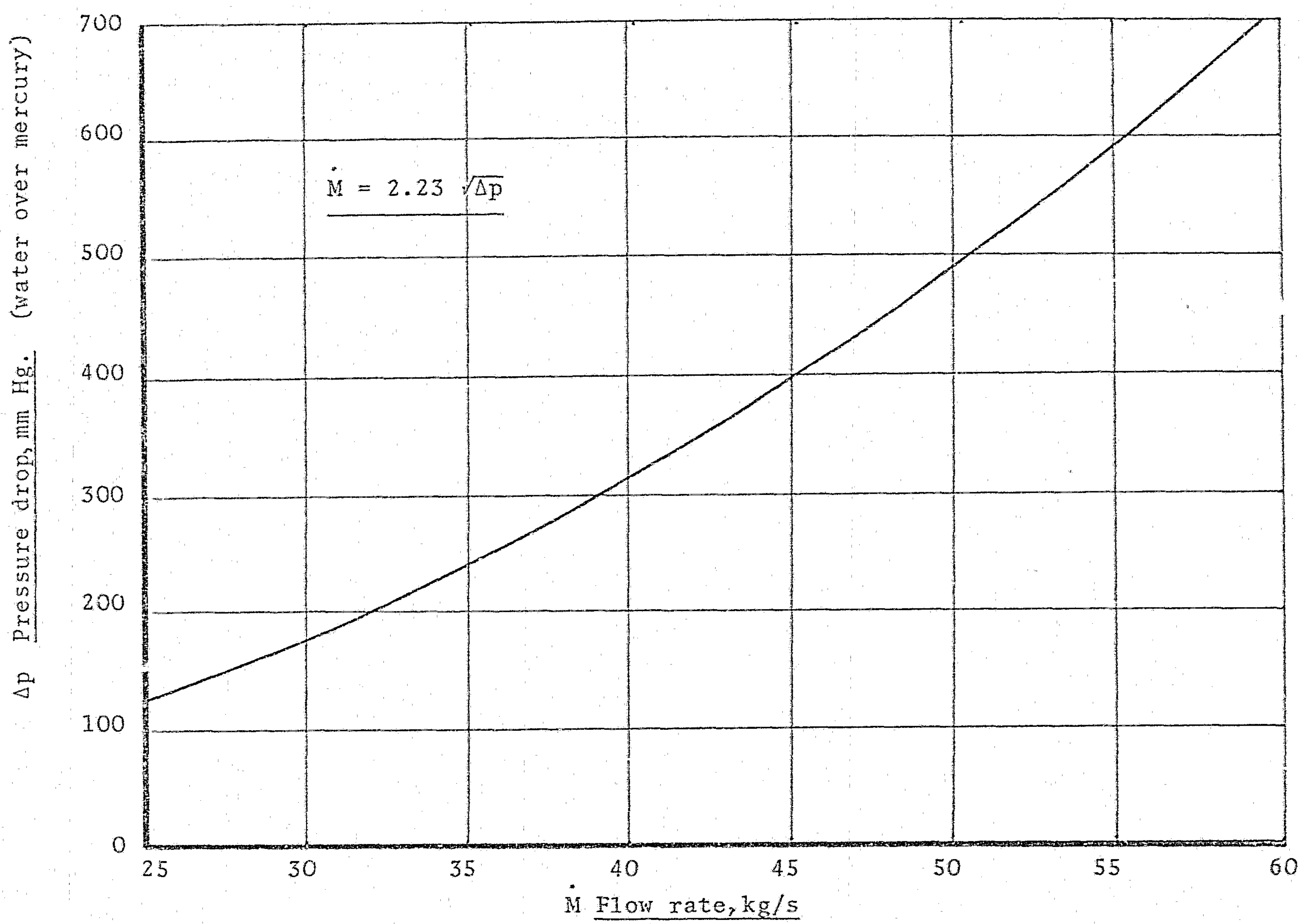


FIGURE C.2: Calibration curve for orifice plate

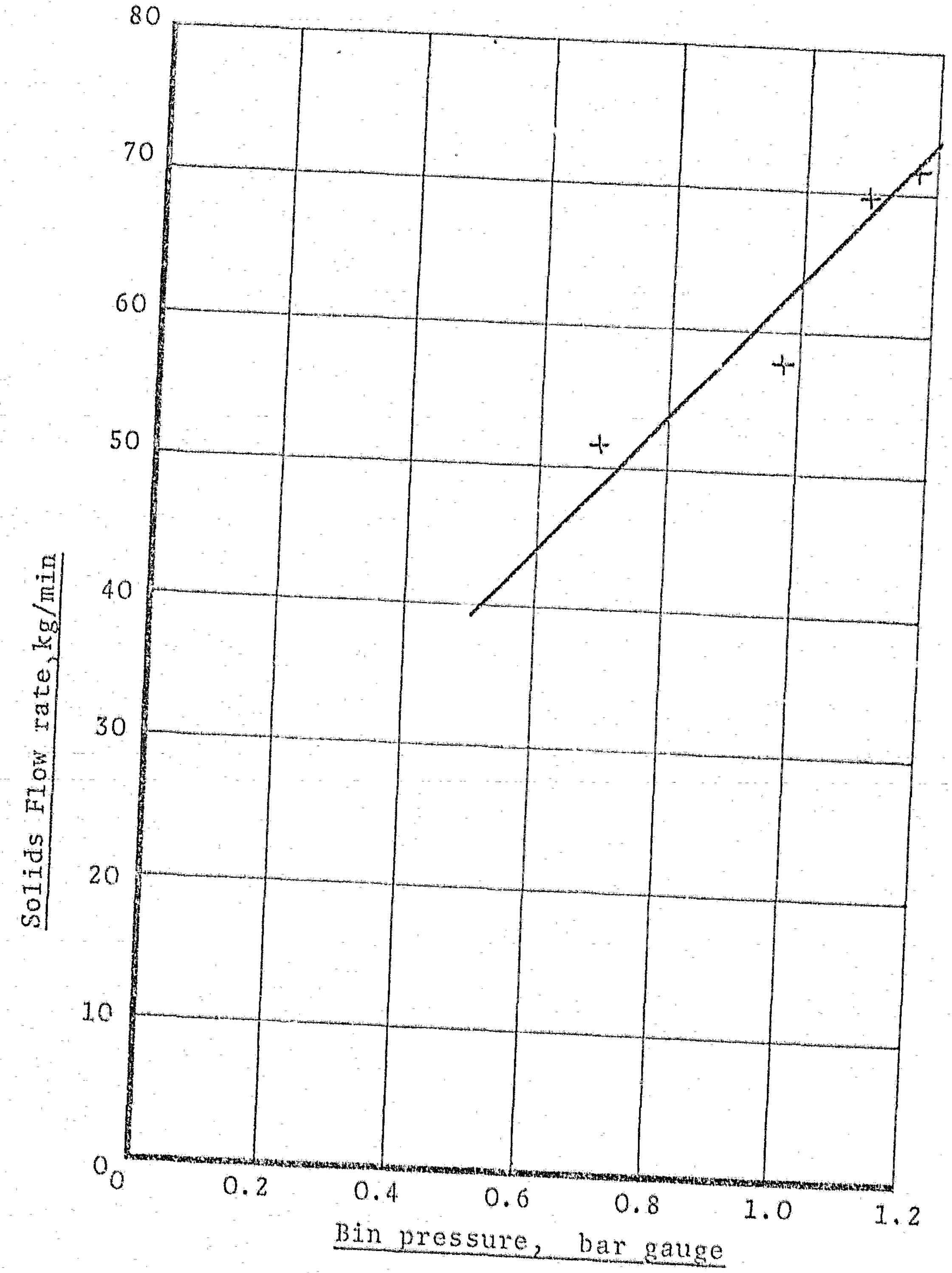


FIGURE C.3: Model feed bin reference curve

APPENDIX D

Comparative mill performance curves

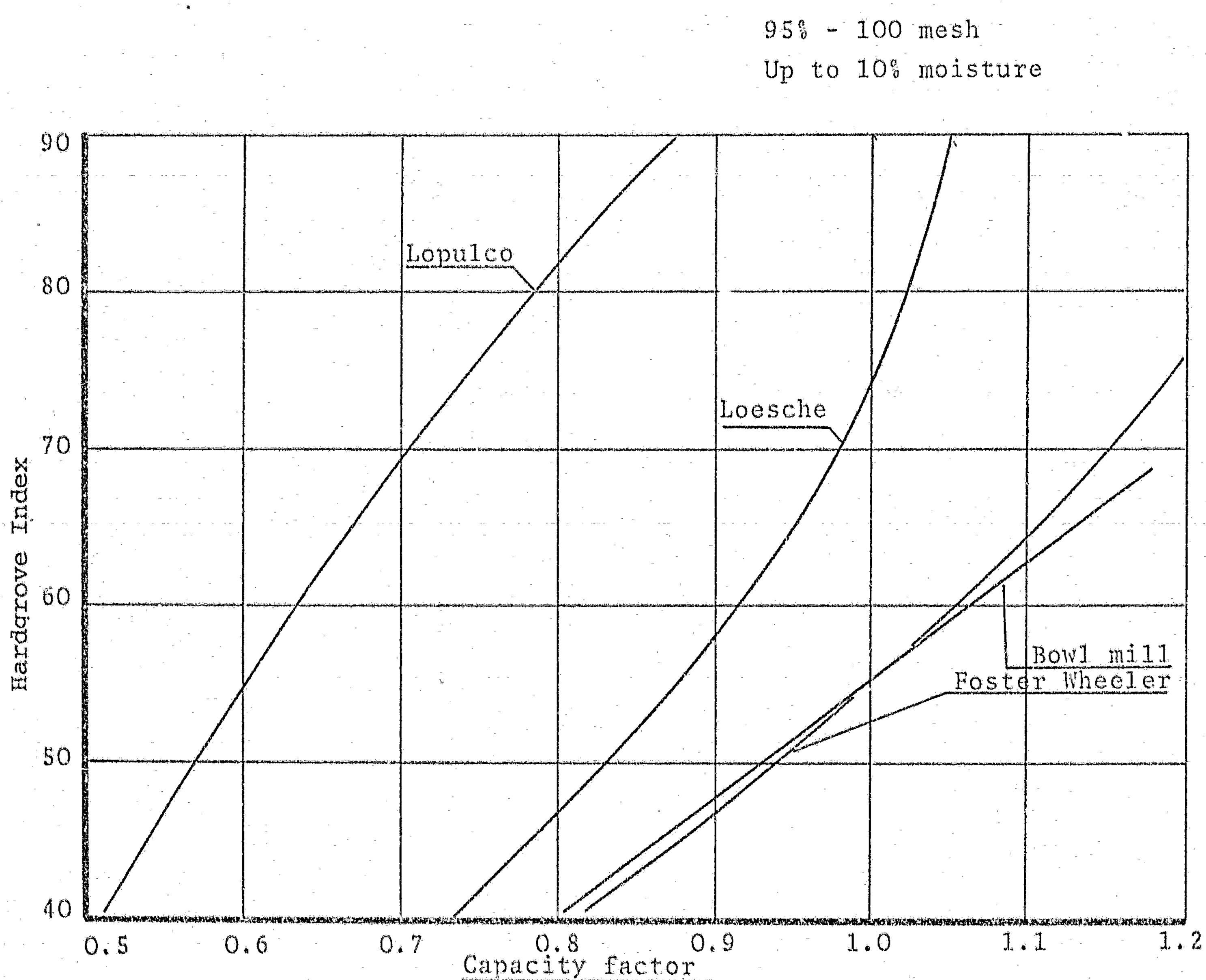


FIGURE D.1 Mill capacity curves vs Hardgrove Index for various types of mill (from M36)

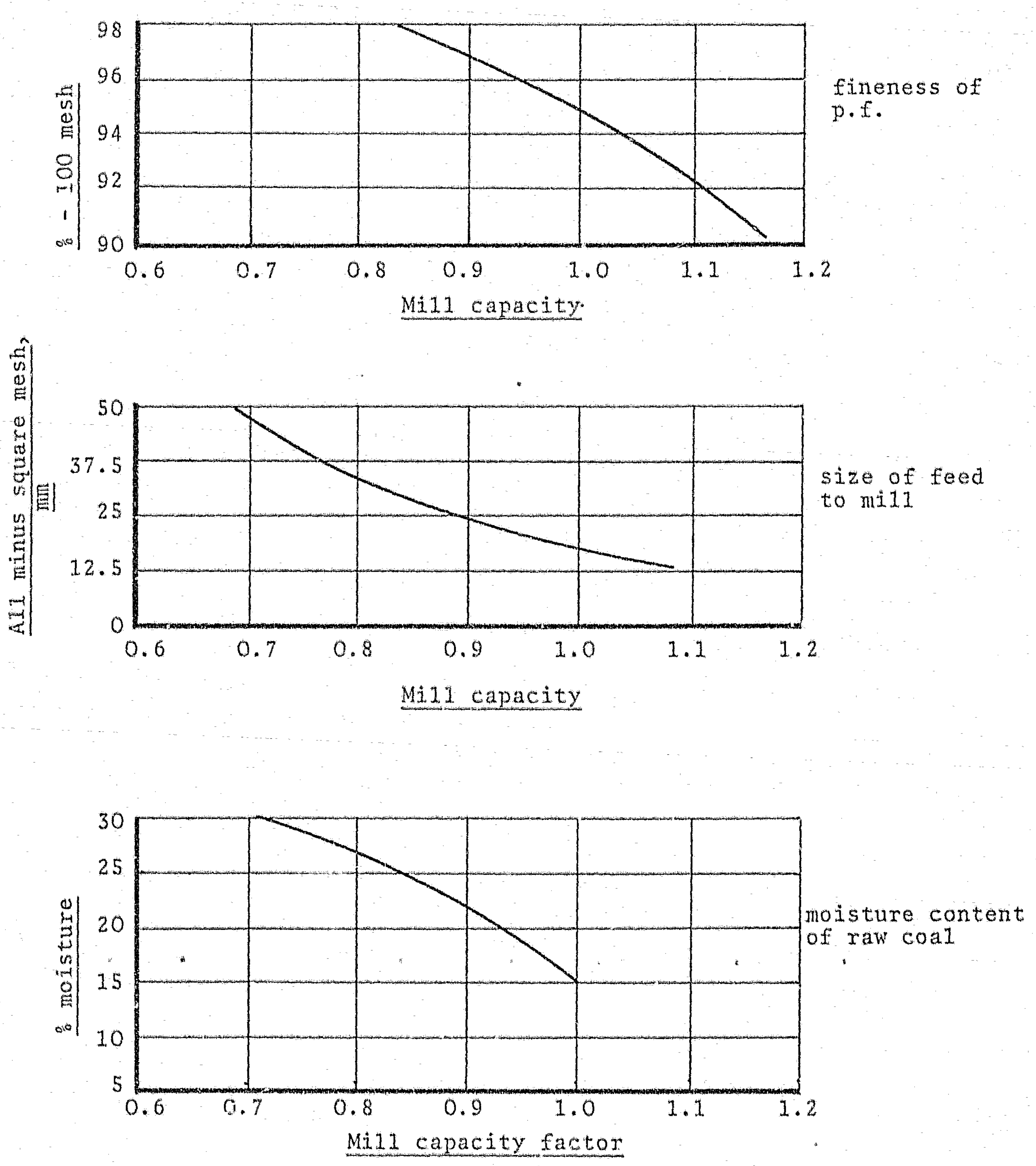


FIGURE D2: Design curves for a roller mill (from M36)

APPENDIX E

Camden mill operating parameters plotted using the uniformity coefficient and average particle size

APPENDIX E

COMMENT ON THE MODIFIED CAMDEN MILL TEST GRAPHS

Figure E1:

The air/fuel ratio at constant load varies only with air increase or decrease, ie, velocity changes within the throat and through the separator. The higher the ratio, the higher the velocities and, therefore, the coarser the product expected. This is borne out by an increase of average particle size with air/fuel ratio for various throat gaps (the narrower the gap, the higher the velocity). For the 89 mm gap, the separator speed was slightly higher, thereby moving the curve to the left, otherwise all things being equal, it would have been more to the right of the 117 mm throat gap curve. The 117 mm gap curve should indicate a finer product than the 102 mm gap throat, but by referring to Figure E2 the shift is perhaps even more apparent.

Figure E2:

The uniformity coefficient of the 117 mm throat product is much higher than for the 102 mm and 89 mm throats, ie, there is less spread of the distribution. This does influence the average particle size as there is less overgrinding. The trend of increasing n with decreasing air/fuel ratio would suggest more efficient operation from an energy point of view at the lower air/fuel ratios for the same average size of particle. In fact, the power consumption is higher for the lower air/fuel ratios due to the higher recirculating load within the mill (ie, lower voidage due to lower velocity). Another reason why the distribution shows less spread for the 117 mm throat is that because the velocities are lower, the chance of sweeping up oversize particles is less, thereby presenting a more even distribution to the separator.

Figures E3 and E4:

Due to temperature changes, the throat velocity might present a different set of curves than those for air/fuel ratio. A lower velocity at the throat will result in a higher mill differential pressure, and consequently lower mill outlet temperature. Also, depending upon the coal moisture content, the air inlet temperature will change to control mill outlet temperature within limits. However, the 89 mm throat curve has been displaced to the left, thereby indicating a different temperature condition of the P.A.

Figures E5 and E6:

To control the final product fineness, the separator rotational speed can be varied. The higher the speed, the more oversize it will return for further grinding, hence increasing the recirculating load within the mill. This will mean a higher pressure drop through the mill. The curves show the effect of using two rows of blades, each row containing a maximum of 90 blades. By removing every second blade, a 45 blade arrangement is achieved. As is to be expected, using the 90 + 90 arrangement gives better classification but also higher power consumption of the separator motor (more blade area). The two sets of curves are not truly comparable since the throat gap for the 90 + 90 blade arrangement is larger. The blade width was decreased to 38 mm with the 90 + 90 arrangement but the slight improvement in fineness is offset by a higher power consumption. The trend, however, is also as expected, that is, increasing particle size with lower separator speed. The uniformity coefficient shows very little trend and it appears, therefore, that the separator speed will not alter the distribution spread, but only the average size. (One point has been ignored since it is obviously a poor sample and not even near the trend of the other points.)

Figures E7 and E8:

As explained previously in the discussion on the operation of the mill, at low loads it is not possible to maintain design air/fuel ratios because the throat and mill velocities are too low to convey the air/coal mixture; ie, when reducing load, the air/fuel ratio must be increased. Therefore, the average particle size will not be reduced to the same extent due to the effect of this increase in air/fuel ratio, as shown in Figure El. However, at the lower loads it is possible to increase separator speed and thus decrease particle size substantially since the mill can then handle the high recirculating load. The curve has been plotted for constant separator speed.

The uniformity coefficient will decrease at lower loads due to there being a thinner bed on the table and thus higher bed pressures exerted by the rolls give an improved grinding action. (One point has been neglected since it appears to represent a poor sample.)

Figures E9 and E10:

The roll pressure is adjusted by the springs on the roll lever arms. The higher the spring tension, the higher the roll pressure on the coal bed. (The rolls are adjusted to leave a gap between table and roll in the no-load condition.)

As would be expected, the highest pressure results in a finer grind, as shown by the decreasing average particle size. It appears that no benefit will be gained by increasing the tension further than about 44 kN. The increase in mill power consumption due to the higher drag of the rolls on the bed must also be considered in order to arrive at an optimum point. It is interesting to note that the higher pressures give a wider distribution spread (lower n). The reason for this could be that the higher pressure causes a higher wave in front of the rolls and a resultant spillage of larger particles and also of fine material which tends to stay on the table at lower pressures. This fine material acts as a cushion and, in fact, impedes grinding of the bed.

Figure E11:

Since the mill diff due to coal is an indication of the recirculating load, the dust loading in the mill can be assumed to be a function of air flow and coal mill diff, ie, it is proportional to

$$\frac{\sqrt{P.A.}}{\text{Coal mill diff}} \quad \text{since } \dot{M}_{air} \propto \sqrt{P.A.},$$

where $\dot{M}_{air}$ = air mass.

The product particle size decreases with increase in dust loading, ie, lower voidage. This trend is to be expected since the lower air flows will entrain less oversize material.

It is interesting to note that the 90 + 90 blade arrangement rotating at 81 r/min gives a curve very close to the curve for the 90 + 45 blade arrangement rotating at 91 r/min (both with 102 mm throat gaps), although the separator power consumption remains the same.

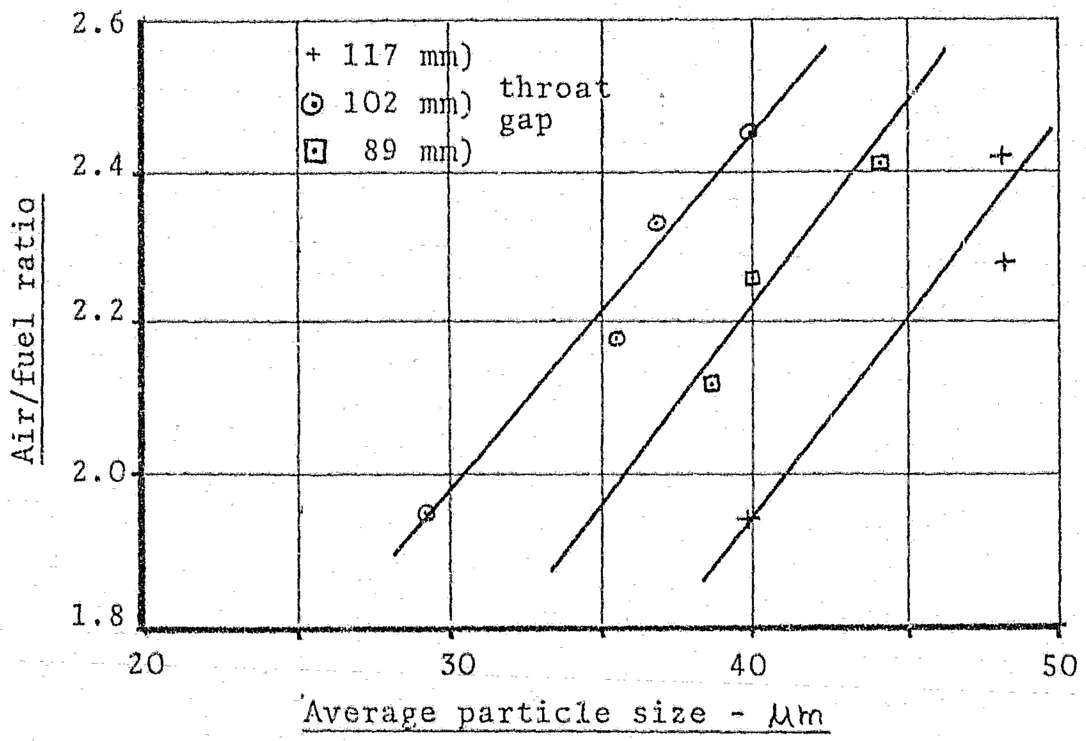


FIGURE E1 : Average particle size vs air/fuel ratio

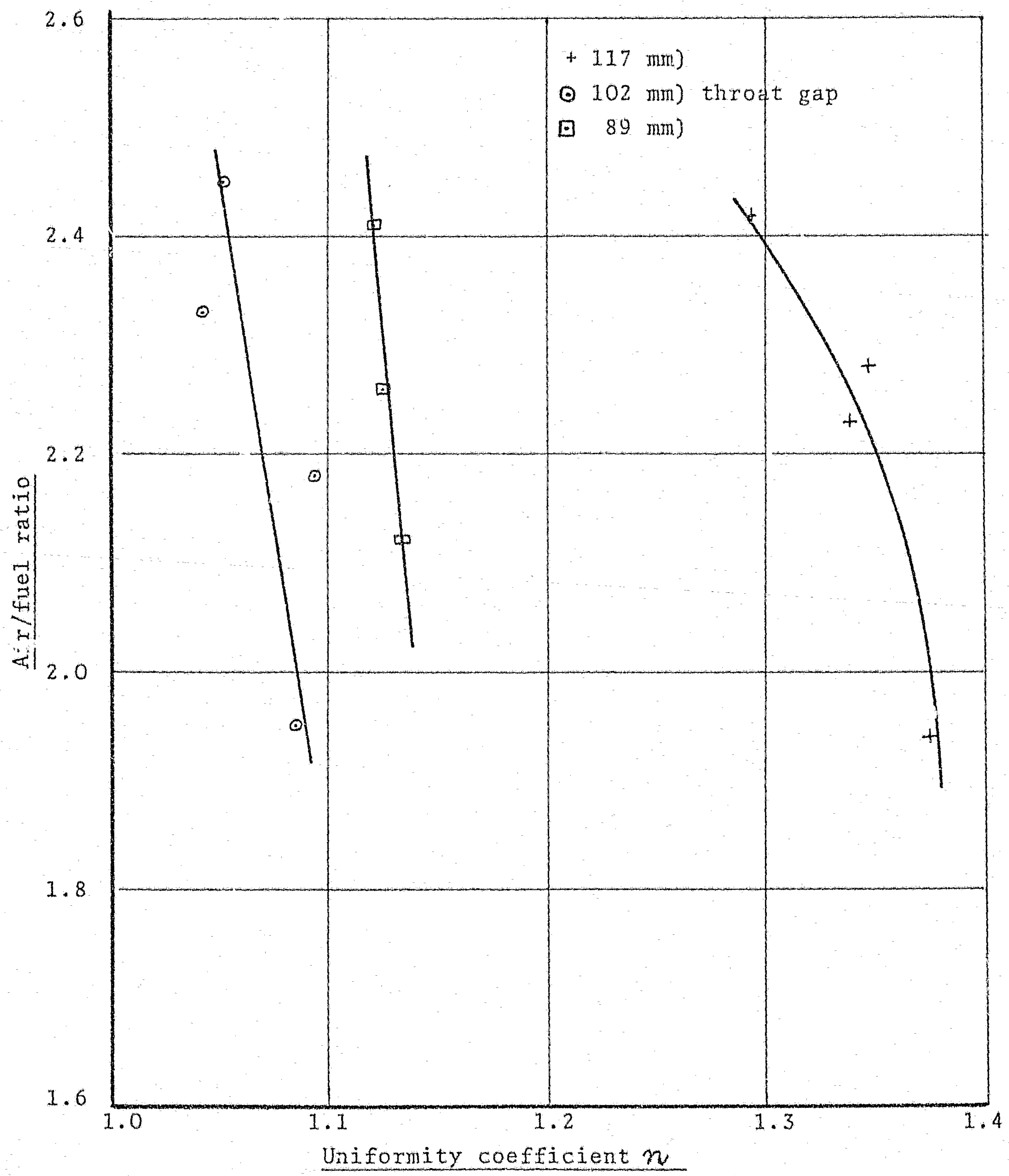


FIGURE E2: Uniformity coefficient n vs air/fuel ratio at constant load

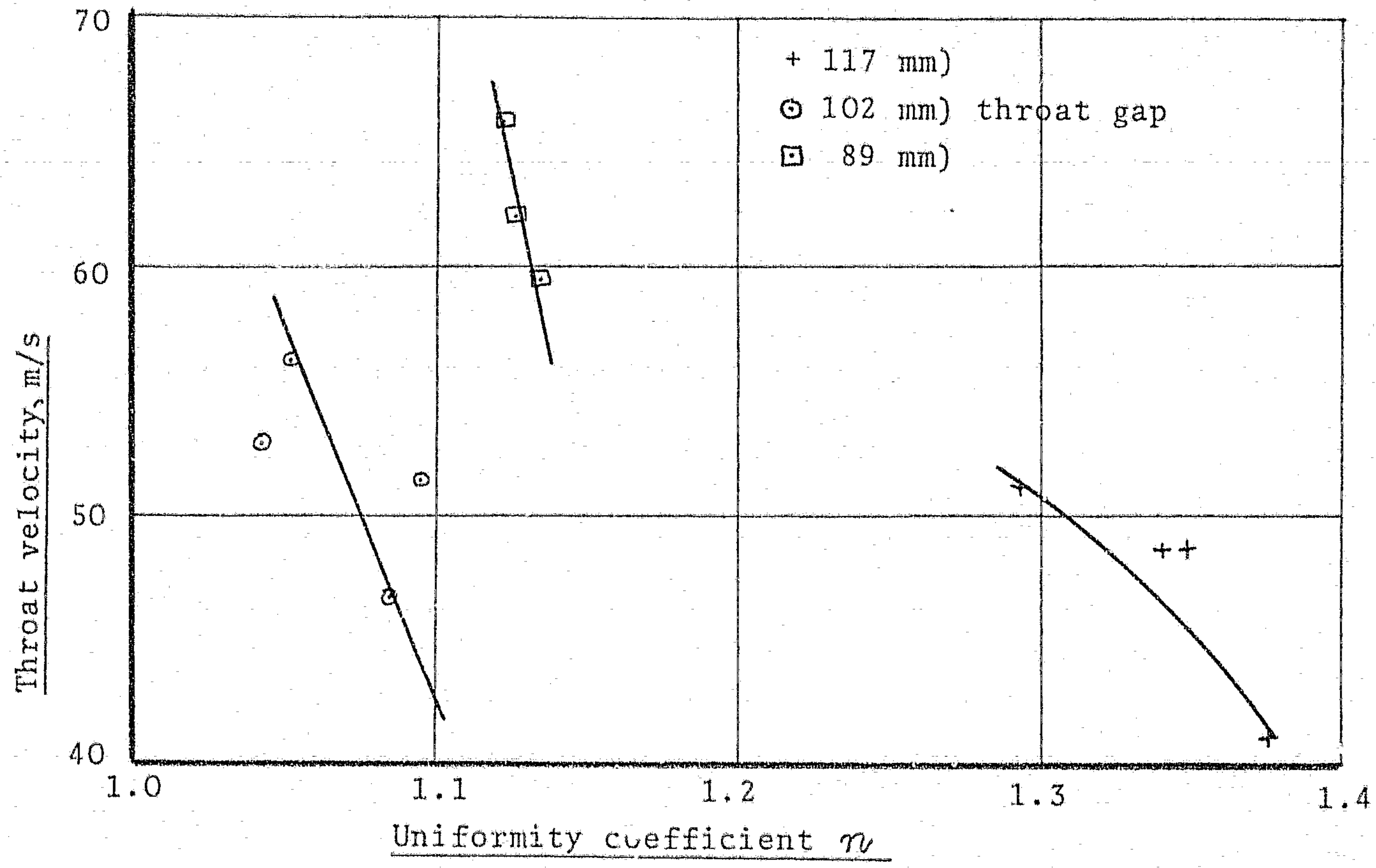


FIGURE E3: Uniformity coefficient n vs throat velocity

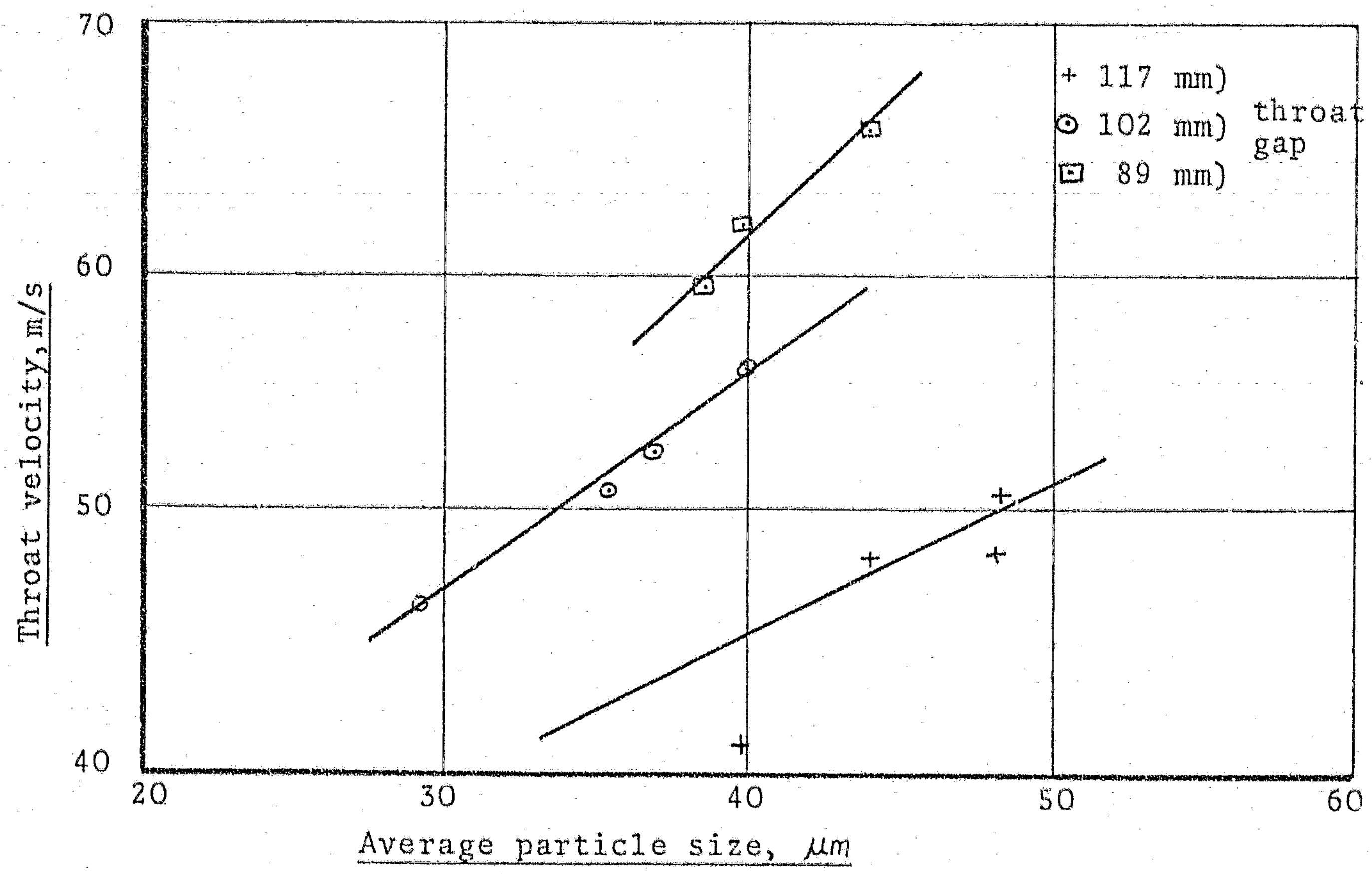


FIGURE E4: Average particle size vs throat velocity

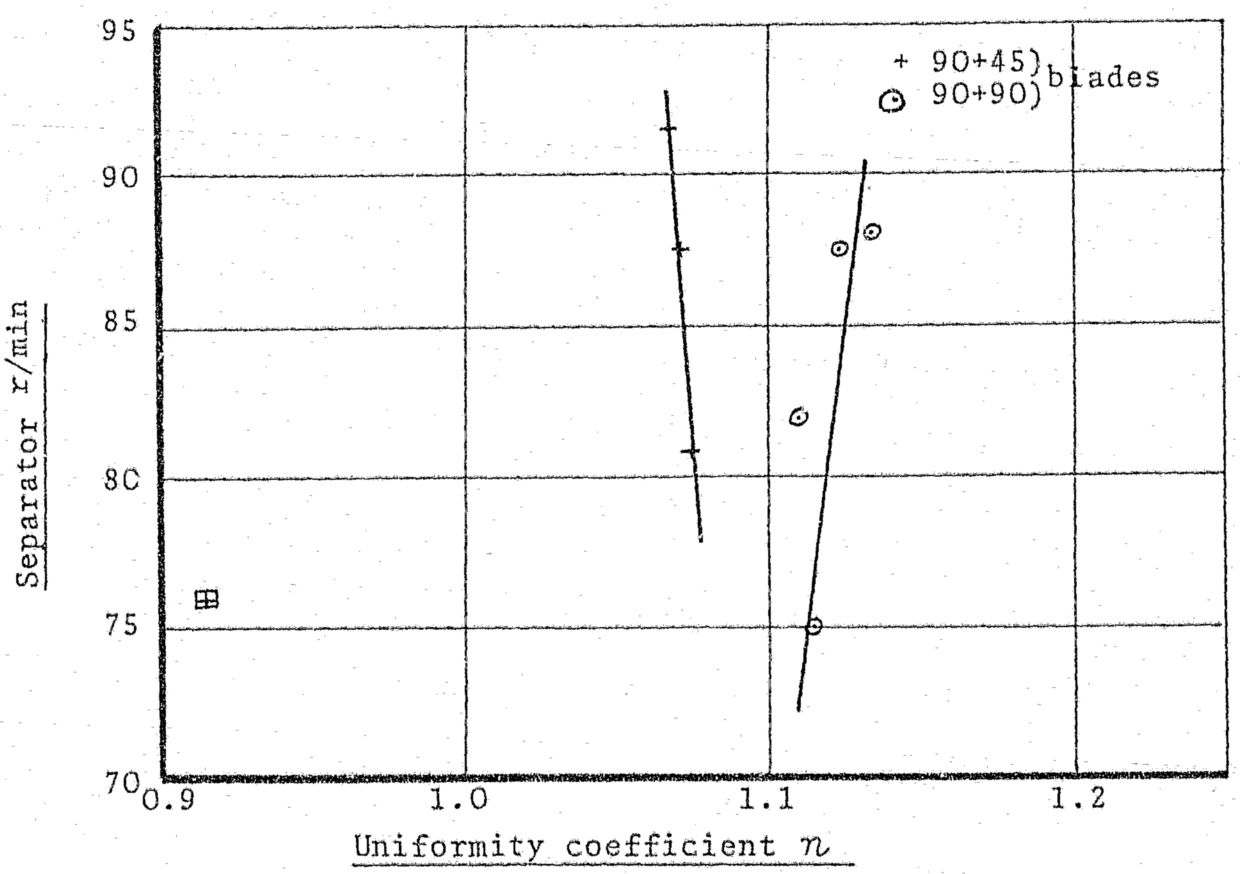


FIGURE E5: Uniformity coefficient n vs separator r/min at constant load

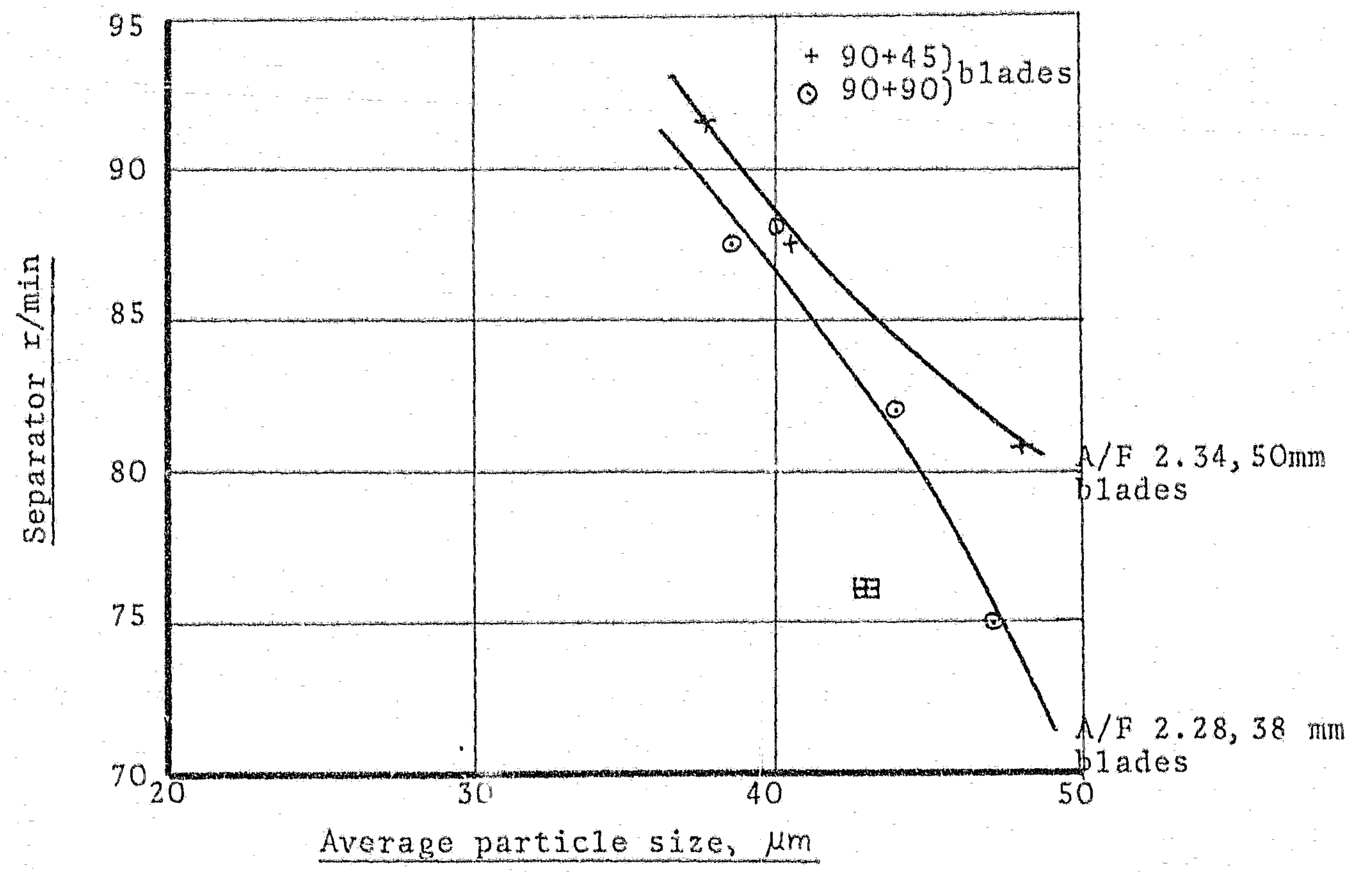


FIGURE E6: Average particle size vs separator r/min at constant load

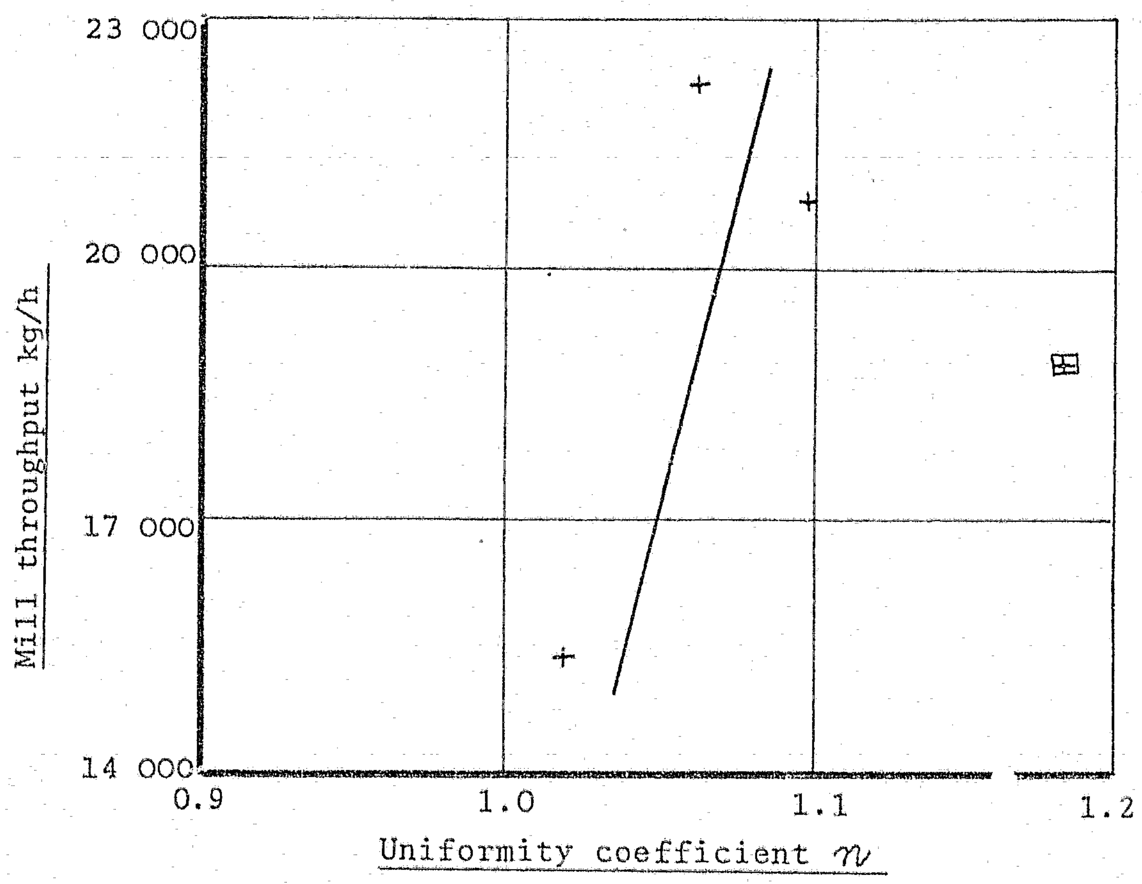


FIGURE E7: Uniformity coefficient n vs mill throughput

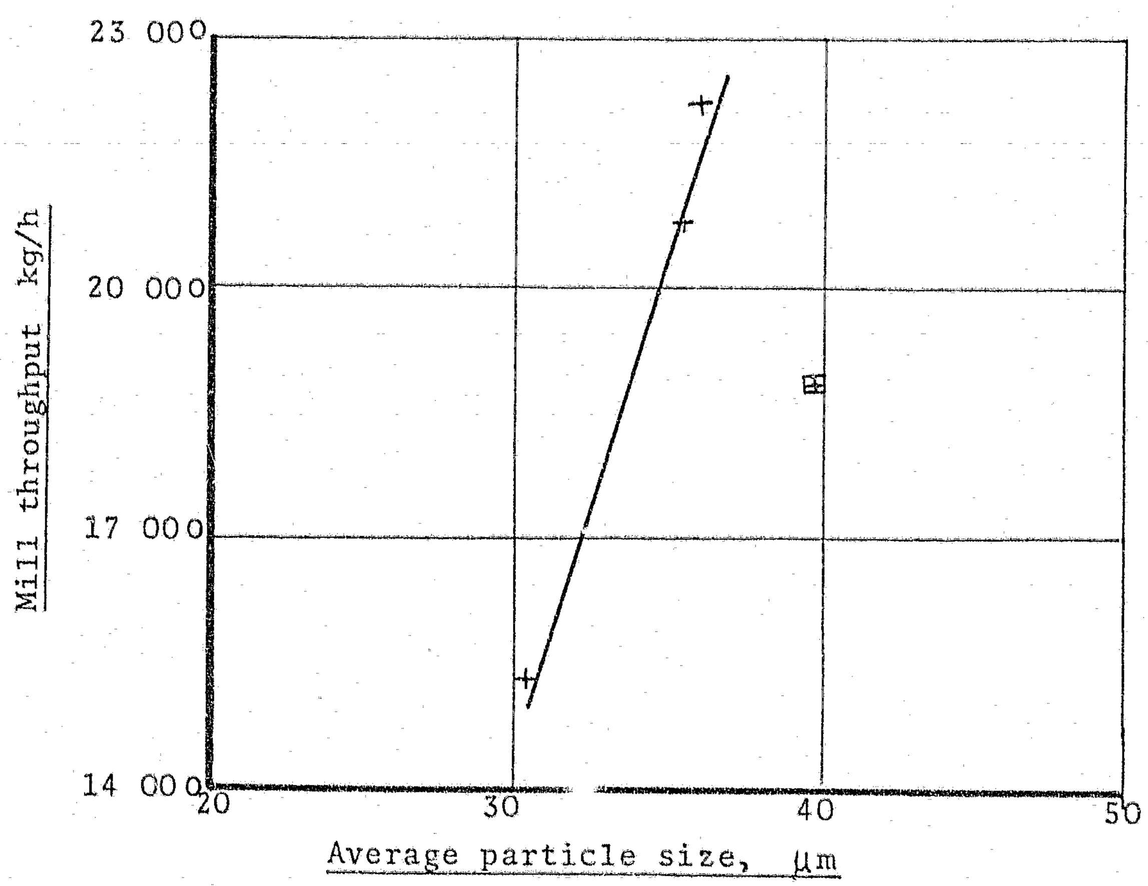


FIGURE E8: Average particle size vs mill throughput

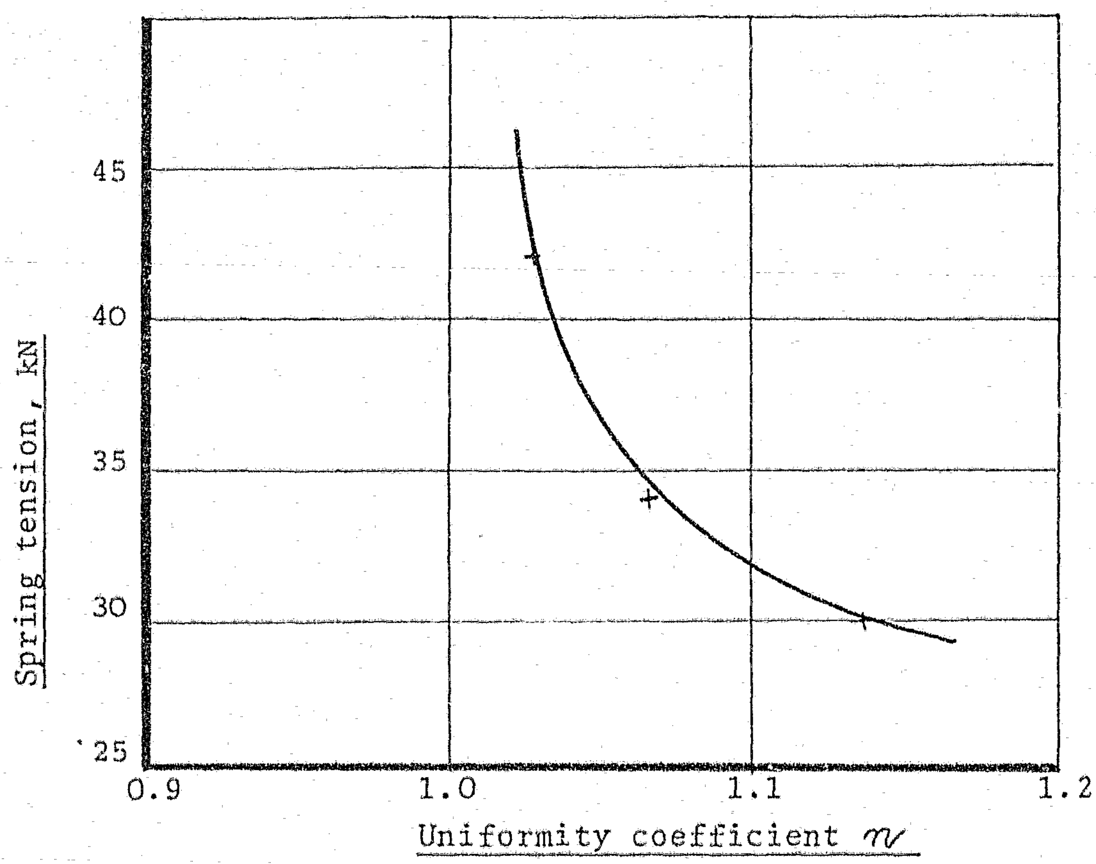


FIGURE E9: Uniformity coefficient n vs spring tension

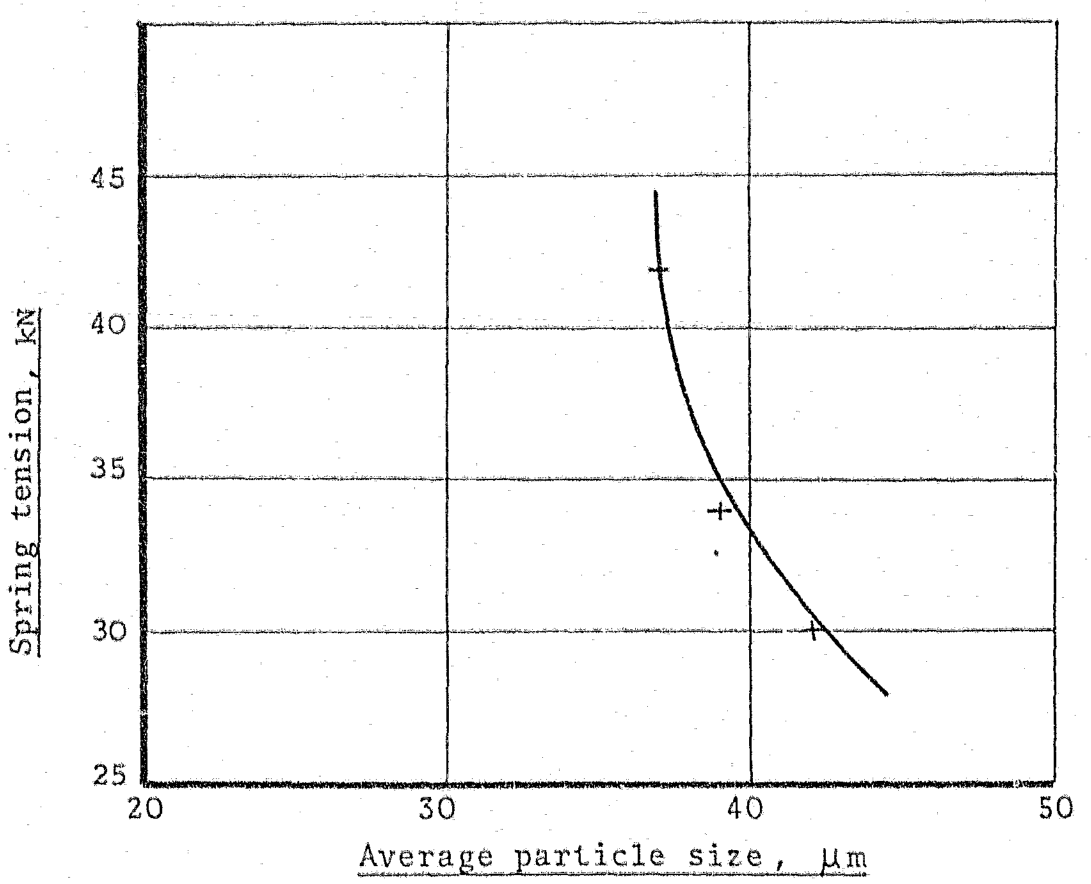


FIGURE E10: Average particle size vs spring tension

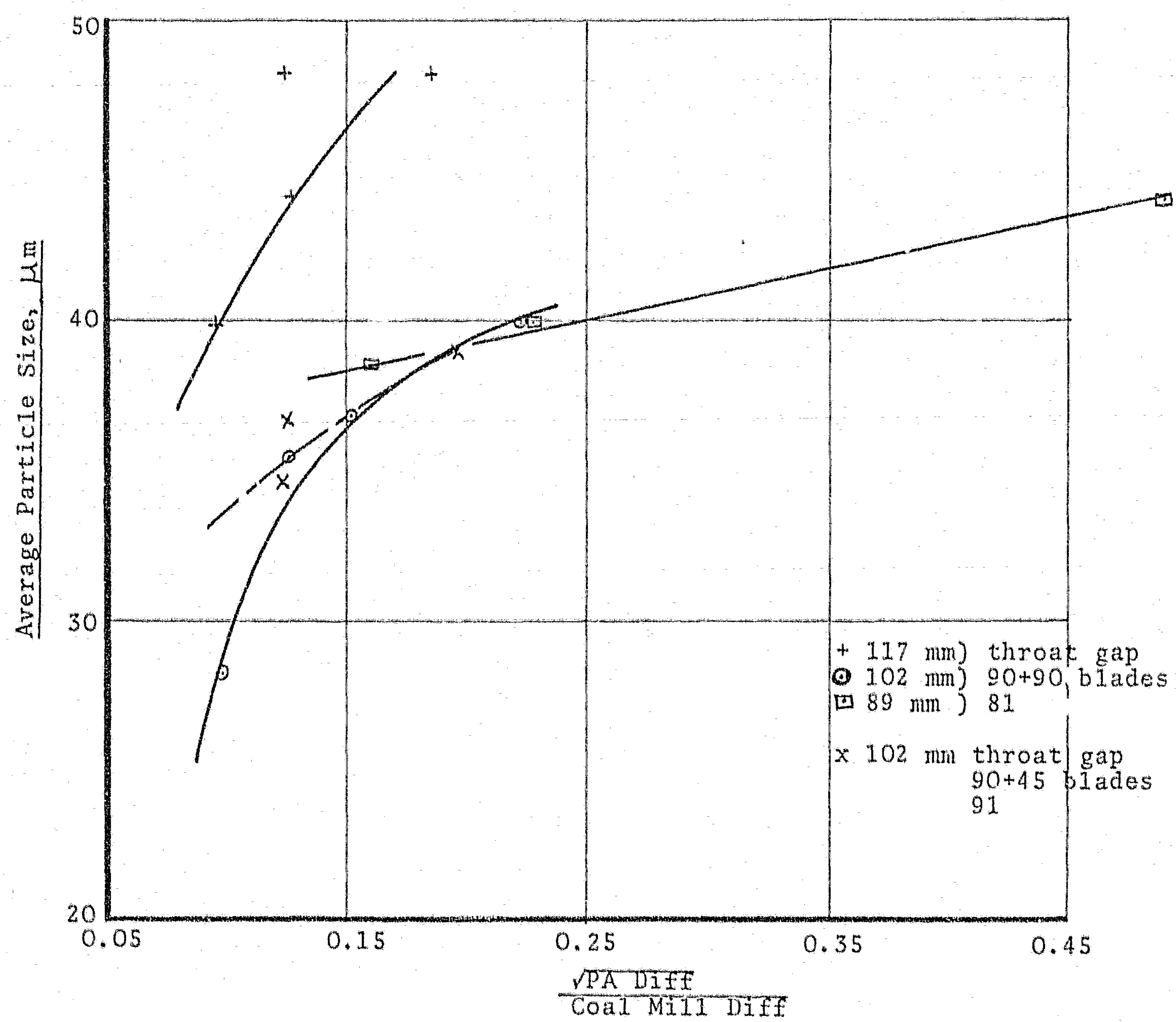


FIGURE E11:Separator dust loading vs average particle size