CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 59-98

A FLOW GAUGE EMPLOYING A RADIOACTIVE TRACER

by

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MINERAL SCIENCES DIVISION

COPY NO. 11

NOVEMBER 12, 1959

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SUMMARY

The development of a fuel gauge to measure the rate of flow of fuel to a jet engine employing a radioactive tracer technique is described. A quantity of iodine-131 is injected into the fuel line by a Diesel injector and its time of transit to a ring of Geiger tubes a short distance down the line is recorded. The time measured may be interpreted as a flow rate with a knowledge of the dimensions of the pipe and specific gravity of the fuel employed.

The flow rates encountered in practice are expected to vary from 500 pounds per hour to 10,000 pounds per hour. The present report deals with flow rates from 1000 pounds per hour to 4000 pounds per hour, the latter being the maximum obtainable in the test bed operation. The results of the tests carried out are given and from these an evaluation of the future possibilities is made.

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CONTENTS

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INTRODUCTION

During the course of experiments on jet engines carried out by the National Research Council, Montreal Road, Ottawa it was found that existing flow gauges did not possess the desired degree of accuracy over the range of flow rates encountered, namely 500 pounds per hour to 10,000 pounds per hour. It was felt that an improvement might be effected by adopting a radioactive tracer technique, and in order to discuss this possibility a preliminary meeting was held at the National Research Council, Montreal Road, on July 11, 1958.

At this meeting the discussions centred around the form in which the tracer was to be employed, and the way in which its passage through the fuel line was to be recorded. A radioactive tracer in pellet form was discussed, since it has the desirable feature of good source definition. However, considerable concern was expressed over the possible damage to internal parts of the engine resulting from the passage of a pellet through this system and it was decided to employ a liquid tracer in a form that would be soluble in the fuel. The question of employing a radioactive gas was raised at a later date, but the prospect of a gas in the fuel system with the resulting possibility of burner extinction caused this line of investigation to be considered impractical.

The method employed to determine the rate of flow of the tracer down the fuel line was governed by practical considerations of the fuel line on the jet engine. The length of the pipe over which the measurement could be made was limited to approximately 12 inches - assuming no modification to the existing system. With this limited space available for both injection of a radioactive tracer and the measurement of its passage, it was decided to measure the time of transit of the radioactive tracer between the point of injection and a Geiger tube detector. The alternative to this was to measure the time of transit between two Geiger tubes situated a known distance apart. However,with the short distance available for both the injection and time measurement, this approach was not considered useful. At the maximum flow rate the time of transit between the injector and detector was expected to be in the neighbourhood of 25 milliseconds.

Two different radioactive tracers have been employed in this investigation. The first was cesium-134 in the form of cesium napthenate. Some difficulties encountered in its preparation and its long half-life (2.3 years) resulted in a decision against the further use of this isotope. A solution of elemental iodine-131 in benzene was obtained as a replacement.

One other approach known as the "total count method"(1) was investigated. This method is based on the principle, that if a fixed quantity of radioactivity is injected into the fuel line each time a test is made, then a detector placed downstream will record a greater total count the more slowly the fuel moves. This arises from the fact that the slower-moving fuel remains in the vicinity of the detector for a longer time and therefore more radioactive disintegrations are recorded, than is the case for the faster-moving fuel. The results obtained by this method are also given below.

EXPERIMENTAL PROCEDURE

Tests performed were of two types, 1) laboratory tests at the Mines Branch on individual components, 2) tests at NRC on a complete system. A block diagram of the apparatus is given in Figure.1. In order to measure the flow rate, the operator depresses the firing switch. This energizes a solenoid, permitting compressed air to actuate a piston, which then causes the injector to operate. This injects a small quantity of tracer into the fuel line. Attached to the piston is a small coil, in the centre of which rests a permanent magnet. This magnet is mounted on the cylinder casing. When the piston moves, the coil cuts the lines of force of the magnet and an electromotive force is developed in the windings of the coil. This induced pulse is employed to initiate the timing circuit, which measures the time of transit from the injector to the detector.

The requirements to be met by the tracer injection device are 1) rapid action, 2) no dribble, 3) quantity injected limited to a fraction of a millilitre, 4) reproducibility, 5) reliability.

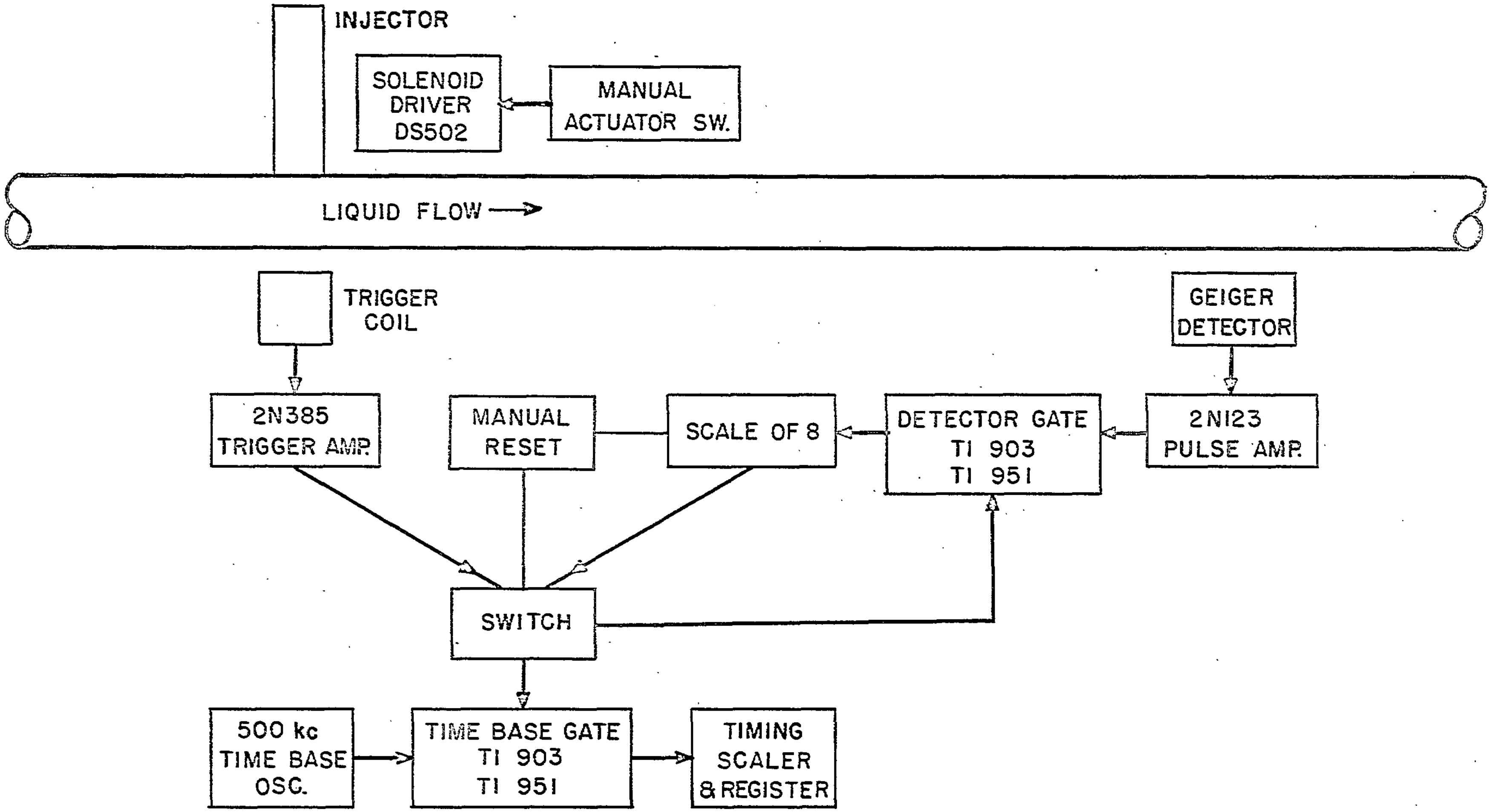


FIG. I-BLOCK DIAGRAM OF ELECTRONIC FLOW RATE METER

The first attempt to meet these requirements, was made employing a simple solenoid valve. When energized, the valve lifted, permitting the radioactive liquid to flow into the fuel line by virtue of pressure exerted by an air cylinder. This device was unsatisfactory, as the penetrating property of the liquid resulted in leaks through the valve, even when closed.

It had been felt from the start, that a form of Diesel injector might be suitable, but some difficulty arose in obtaining one of a satisfactory design. However, one was supplied by the Fuels and Lubricants Section of National Research Council, which has met the requirements listed above and which has been in use for some time. The particular model employed is a G.M. HV-6.

The detectors employed have been Geiger tubes, these being considered more rugged and less space-consuming than photomultiplier tubes which in addition require a scintillation material.

Requirements in a suitable Geiger tube are, that it should have minimum dead-time, that the active volume be large (for better efficiency in counting the gamma rays), but that the detecting zone be narrow for good time resolution. The requirement of short dead-time led to the adoption of halogen-quenched tubes. The dead-time of this system was further reduced by employing a number of Geiger tubes operated in parallel. Two configurations of Geiger tubes have been employed. The first consisted of a ring of four

Victoreen 1B88 tubes, which are about one-half inch long and one-quarter inch in diameter, placed tangentially around the fuel pipe. This tube type proved unreliable in our operations and has been replaced with a Philips 15803 tube. This tube is about one inch in length and one-half inch in diameter. Five of these have been arranged so that the ends butt against the fuel line. The injector and detector assemblies are shown in Figure 2.

The timing circuit consists of a 500 kilocycle crystal-stabilized oscillator, whose output is fed to an electronic counter. The output from this oscillator is normally biased "off", but the initiating pulse from the coil on the injector piston operates a switching circuit which permits the counter to begin recording. As the activity flows down the line, it passes the Geiger tube detector and as it passes, the oscillator output is returned to the "off" position. The count registered on the counter may be recorded as a time interval, since each count represents an elapsed time of 2 microseconds. This in turn may be interpreted as a flow rate from a knowledge of the dimensions of the fuel line. The results obtained in the tests are compared with the readings obtained with a Rotameter. The desired accuracy of the fuel gauge is one-half of one percent and in order to fall within this limit the time of arrival at the Geiger tubes must be measured to within 100 microseconds, at the fastest flow rates.

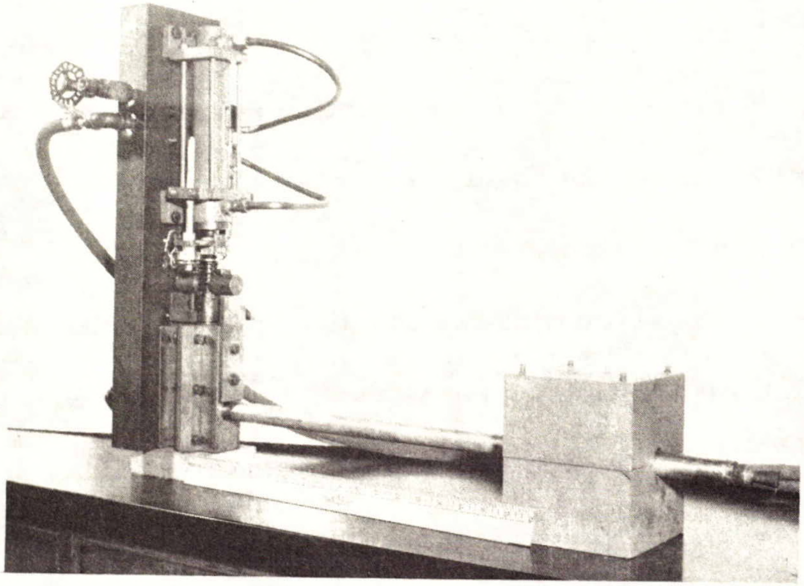


Figure 2. - Injector and Detector Assembly

In order to overcome the possibility of background pulses affecting the results, the output from the Geiger tubes does not place the oscillator output in the "off" position directly, but passes instead to a scaling strip. This scaling strip consists of a scale of eight and it is the output from this scaling strip that gates the oscillator output. A scale of eight is employed so that one or two background pulses can be tolerated without disrupting the time-measuring system. As the radioactive solution passes the Geiger tubes the additional counts required to trigger the scale of eight will occur very rapidly.

In estimating the quantity of activity that should be injected each time a measurement is to be made, it is necessary to take into consideration the rate of flow of the fuel and maximum time permitted to record the eight counts and still maintain the desired accuracy. For the fastest flow rates this leads to an estimate of 1/2 millicurie per shot. As a result of this it is necessary to load the reservoir for the injector with about 20 millicurie of tracer to make forty measurements at the fastest rate.

The test bed assembly as set up at NRC, Montreal Road, is shown in Figure 3. In comparing Figures 2 and 3 it may be noted that a considerable quantity of lead shielding was added at the test site. About fifty percent of this was required to shield the operators.

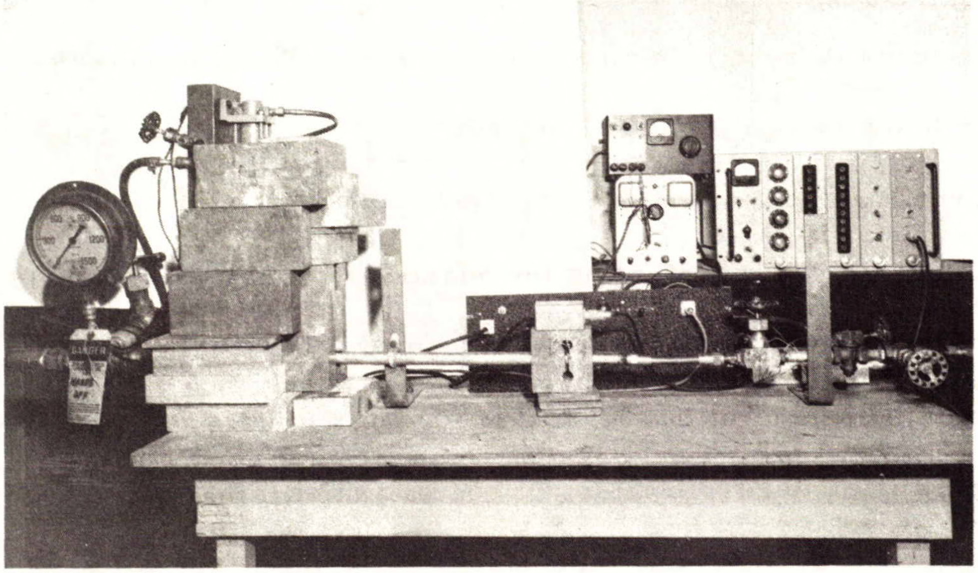


Figure 3. - Test Bed Assembly

The associated electronics including time scaler and detector are shown in Figure 3. A circuit diagram for the switching circuit is given in Figure 4. This has been discussed more fully elsewhere(2).

During the first tests with iodine-131 as a tracer, it developed that the iodine formed a ferrous iodide with the iron in the injector system and stuck to the walls of the injector. As a result it did not find its way into the fuel line. This difficulty was overcome by the addition to the benzene solution of a small quantity of styrene. Styrene, as an unsaturated hydrocarbon, complexes the iodine and prevents its reaction with the iron. Although this additive has certainly made possible the use of iodine-131 as a tracer, it is not established that it is one hundred percent effective in picking up all the iodine.

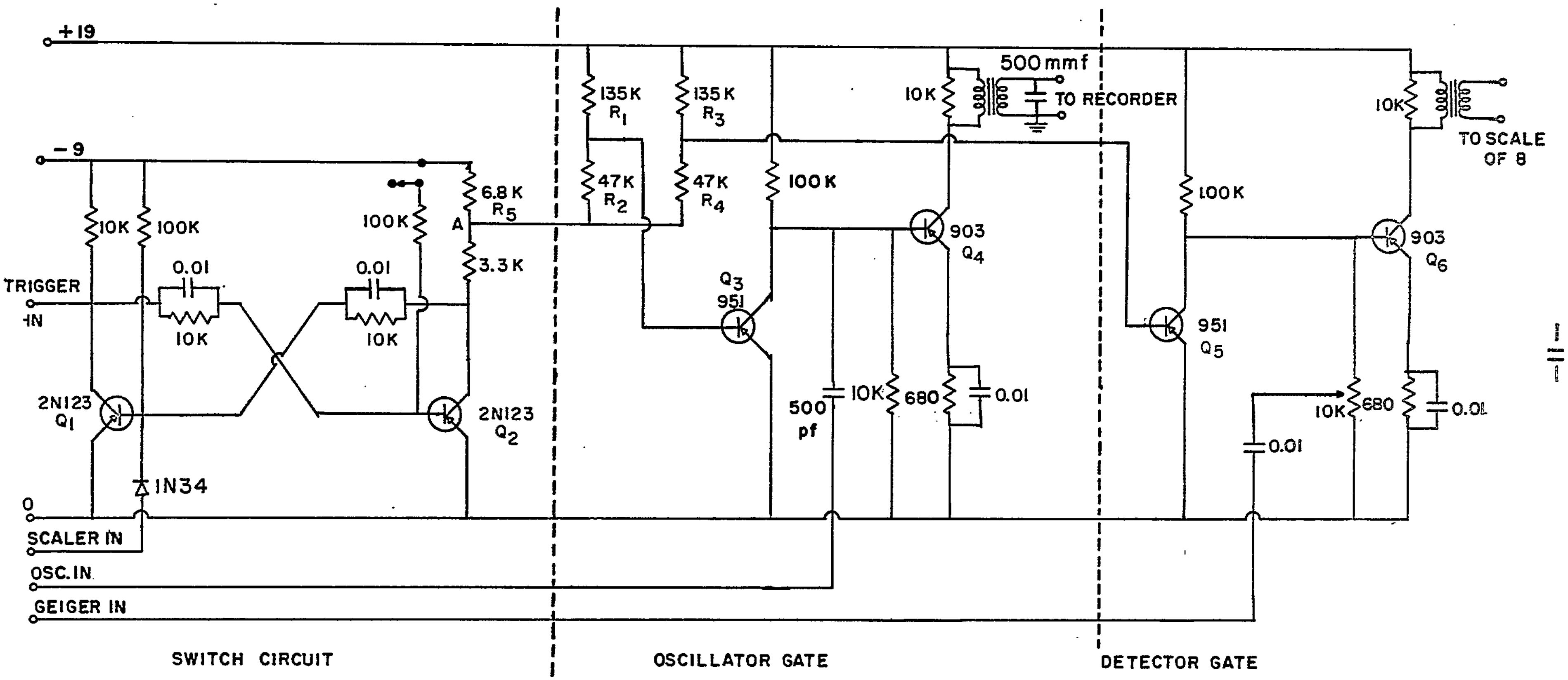


FIG. 4 - CIRCUIT OF TIMING UNIT

EXPERIMENTAL RESULTS

The results of several experimental runs are given in the tables below. In the column indicating the time of transit, each unit measures 16 microseconds. The results of all runs are given together with the average for each, the deviation from the average, and the percent deviation. These are important for the statistical evaluation of the method.

The actual flow rates are calculated from the relation

$$\text{Flow rate} = 63.9 \frac{d^2 s}{n} \times \rho \times 10^{-5} \text{ lb/hr}$$

where d = the inner diameter of tube in inches,

s = the distance from injector to detector in inches,

ρ = specific gravity of fuel,

n = number shown on the recorder.

The relation between recorded count and the reciprocal of the Rotameter reading for the results of Table 1 are shown in Figure 5. Similar results are recorded in Tables 2 and 3 and Figures 6 and 7 for subsequent trials.

TABLE 1

Results of Test Run No. 1

Rotameter lb/hr	Recorded Count (time of transit)	Deviation from Average	Per cent Deviation
2110	26900	+ 500	1.8
	26100	- 300	1.1
	26200	- 200	0.8
	27300	+ 900	3.4
	25700	- 700	2.7
1460	40400	+ 800	2.0
	37300	-2300	5.8
	38200	-1400	3.5
	40400	+ 800	2.0
	41700	+2100	5.3
2100	29600	+1900	6.9
	29300	+1600	5.8
	27800	+ 100	0.4
	27200	- 500	1.8
	26600	-1100	4.0
	25700	-2000	7.2
	27200	- 500	1.8
	28000	+ 300	1.1
3500	18100	- 500	2.7
	18900	+ 300	1.6
	18500	- 100	0.5
	18900	+ 300	1.6

Rotameter lb/hr	Average Recorded Count	RA Flow Gauge lb/hr	% Difference
2110	26400	2630	24.6
1460	39600	1740	19.2
2100	27700	2500	19.1
3500	18600	3720	6.3

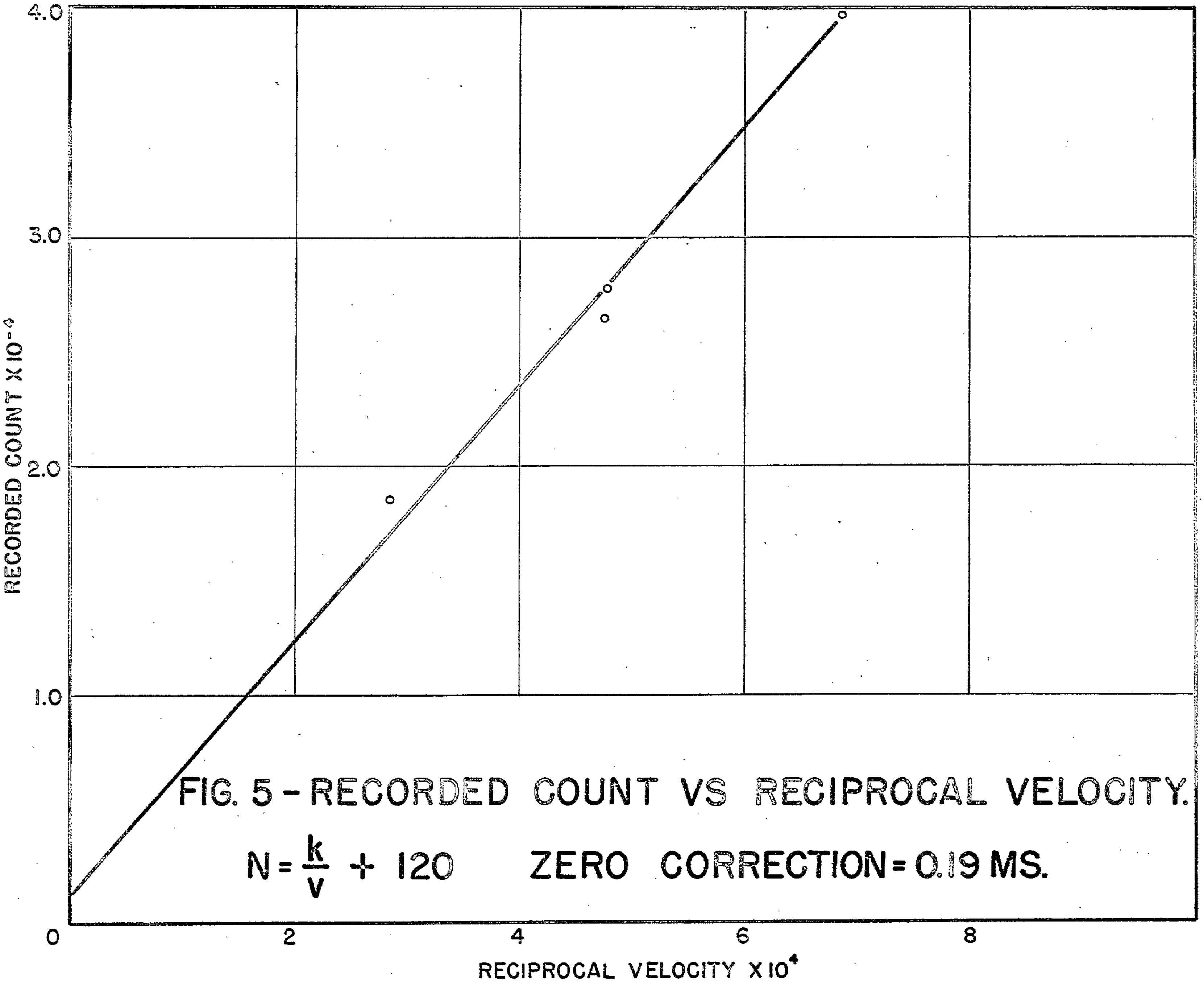


FIG. 5 - RECORDED COUNT VS RECIPROCAL VELOCITY.

$N = \frac{k}{V} + 120$ ZERO CORRECTION = 0.19 MS.

TABLE 2

Results of Test Run No. 2

Rotameter lb/hr	Recorded Count (time of transit)	Deviation from Average	Per cent Deviation
1450	34540	-250	0.7
	35310	+430	1.2
	33690	-1190	3.8
	35200	+320	0.9
	35670	+790	2.3
2030	29320	+2110	7.8
	26880	-330	1.2
	27180	-30	0.1
	24650	-2560	9.5
	29670	+2460	9.0
	25570	-1640	6.0
3020	21450	+1000	4.9
	21370	+920	4.5
	19430	-1020	5.0
	19670	-780	3.8
	20060	-390	1.9
	20690	+240	1.2
3990	16440	-200	1.2
	16920	+280	1.7
	15190	-1450	8.7
	18000	+1360	8.2
1000	49970	+4170	9.2
	52130	+6330	13.8
	43300	-2500	5.5
	49220	+3420	7.5
	36960	-8840	18.4
	46550	+750	1.6
	39730	-6070	13.2
	48680	+2880	6.2
2480	23000	-1180	4.9
	25050	+870	3.6
	27730	+3550	14.7
	23460	-720	3.0
	21950	-2230	9.2
	25190	+1010	4.2
	23020	-1160	4.8
	24040	-140	0.6

(cont' d)

TABLE 2 (cont'd)

Rotameter lb/hr	Recorded Count (time of transit)	Deviation from Average	Per cent Deviation
3480	18320	- 300	1.6
	17340	-1280	6.9
	17300	-1320	7.1
	19650	+1030	5.5
	19190	+ 570	3.1
	20700	+2080	11.2
	19270	+ 650	3.5
	19350	+ 730	3.9
	17550	-1070	5.8
	17470	-1150	6.2
	18660	+ 40	0.2
1000	53610	- 40	0.1
	53300	- 350	0.7
	52130	-1520	2.8
	53410	- 240	0.5
	55790	+2140	4.0

Rotameter lb/hr	Average Recorded Count	RA Flow Gauge lb/hr	% Difference
1000	53650	1130	+13.0
1000	45800	1320	+32.0
1450	34790	1740	+20.0
2030	27210	2230	+ 9.9
2480	24180	2510	+ 1.2
3020	20450	2950	- 2.3
3480	18620	3260	- 6.3
3990	16640	3650	- 8.5

TABLE 3

Results of Test Run No. 3

Rotameter lb/hr	Recorded Count (time of transit)	Deviation from Average	Per cent Deviation
4000	13400	- 800	5.6
	15300	+1100	7.8
	14000	- 200	1.4
	13300	- 900	6.3
	14600	+ 400	2.8
	14000	- 200	1.4
	13300	- 900	6.3
	15900	+1700	12.0
	14100	- 100	0.7
	14500	+ 300	2.1
	13000	-1200	8.5
	15400	+1200	8.5
3500	16700	+1200	7.7
	15100	- 400	2.6
	16500	+1000	6.5
	15900	+ 400	2.6
	14600	- 900	5.8
	14400	-1100	7.1
3000	15700	-2600	14.2
	20600	+2300	12.6
	19500	+1200	6.6
	17300	-1000	5.5
	18300	--	0
	17000	-1300	7.1
	19900	+1600	8.7

Rotameter lb/hr	Average Recorded Count	RA Flow Gauge lb/hr	% Difference
4000	14200	4520	13.0
3500	15500	4140	18.3
3000	18300	3510	17.0

FIG. 6 - RECORDED COUNT VS RECIPROCAL VELOCITY

$N = \frac{k}{v} + 410$ ZERO CORRECTION = 0.66 MS

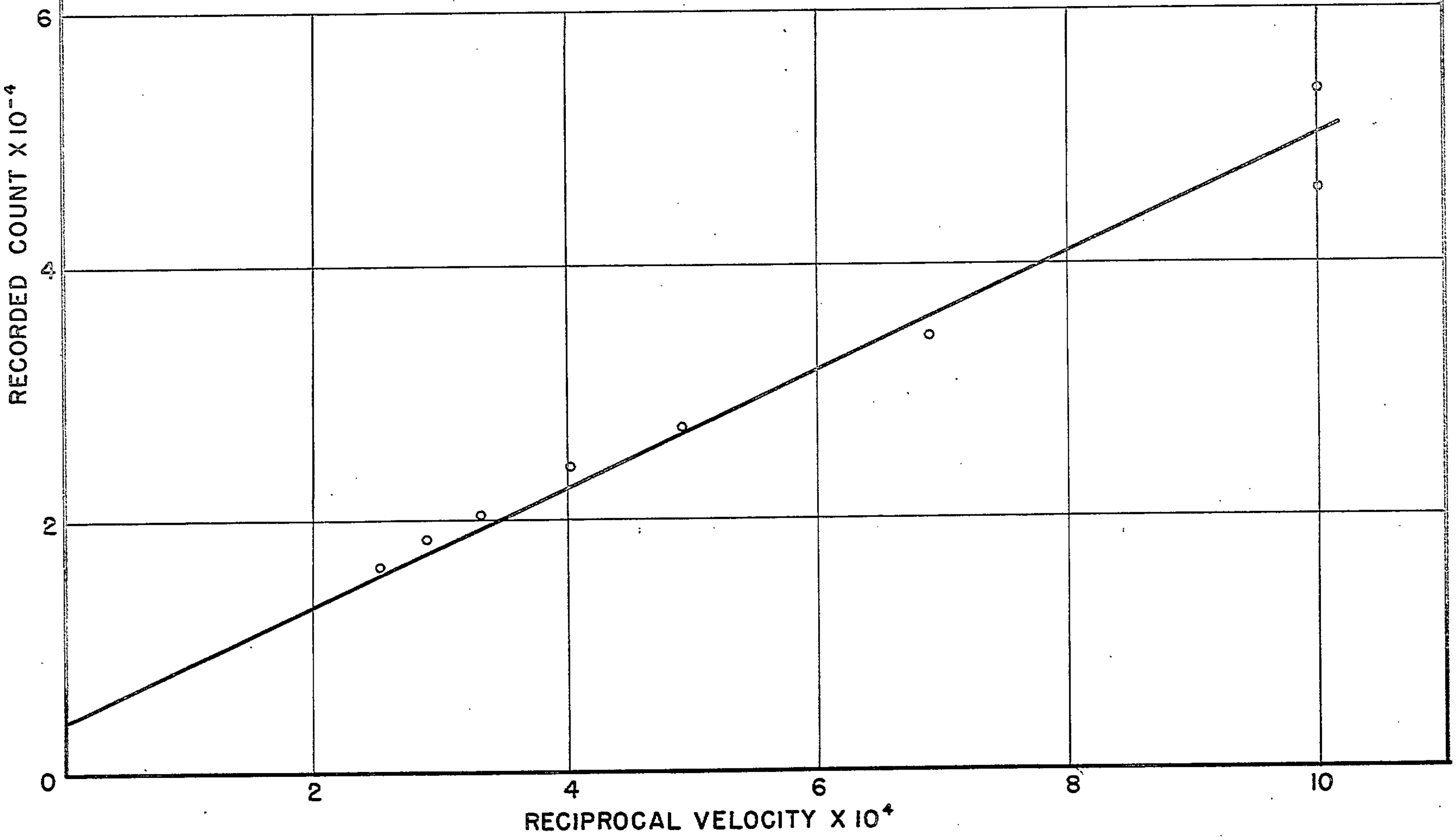
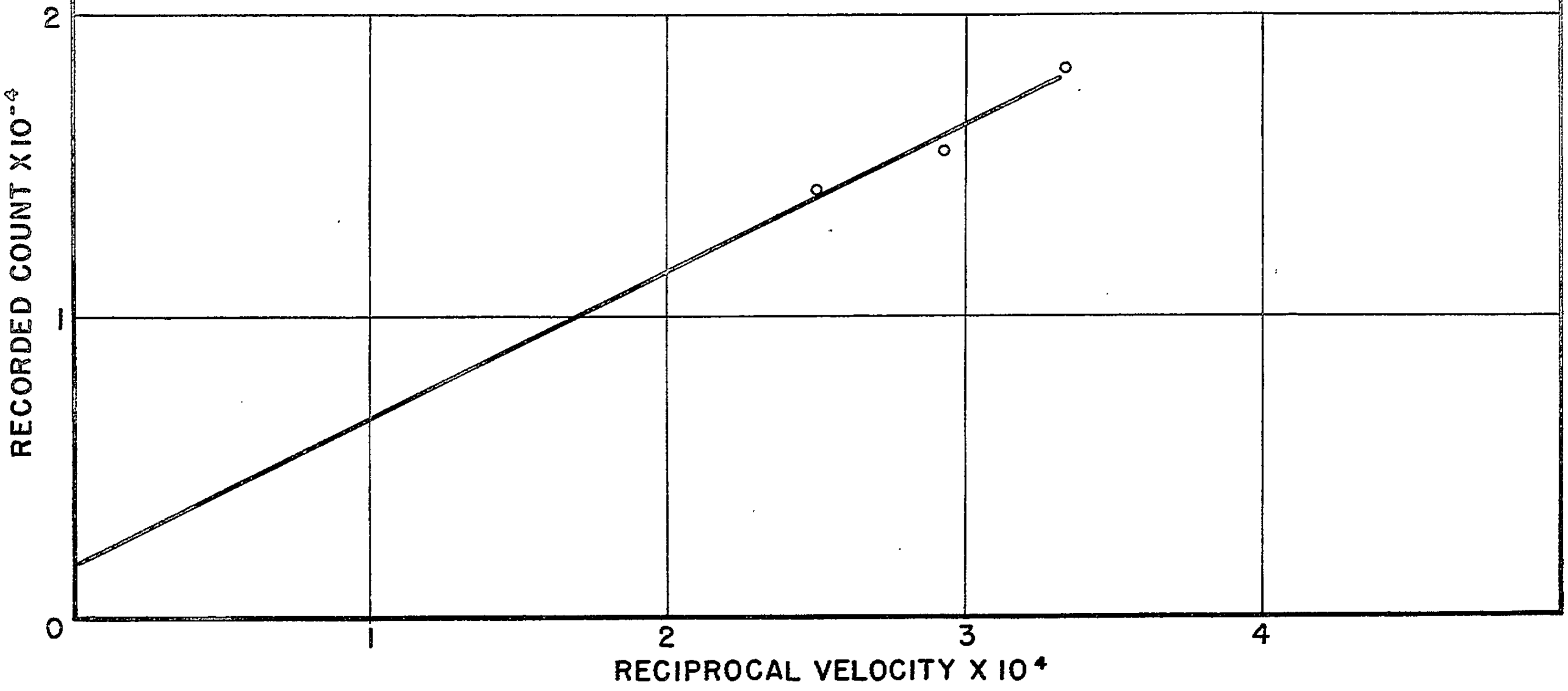


FIG. 7- RECORDED COUNT VS RECIPROCAL VELOCITY.

$N = \frac{k}{v} + 190$ ZERO CORRECTION = 0.30 MS.



In Figures 5, 6 and 7 it may be noted that the straight line does not pass through the origin. This is attributed to the initial timing pulse occurring at the beginning of the injection and not at the actual instant when the tracer itself becomes part of the flow. The equation of the curve is given in each figure and the "zero correction" is obtained by the intercept on the ordinate.

THE TOTAL COUNT METHOD

The Diesel injector is ideally suited for this type of experiment, since it is designed to inject equal quantities at a given throttle setting. In order to obtain reasonable statistics, a standard deviation of 1/2 percent, it is necessary to record 40,000 counts. (In the case of radioactive disintegration, the standard deviation is equal to the square root of the total count). The results listed in Table 4 for the total count were obtained with a scintillation counter when the activity injected per shot was the order of 0.4 millicurie.

TABLE 4

Results of Total Count Method

Trial	Total Count
1	1792
2	2192
3	4728
4	3152
5	2088

It may be seen immediately, that insufficient counts were obtained in this case for the method to be useful. Some improvement might be effected by alterations in the electronic circuit, but sufficient improvement to increase the total count by a factor of 50 is considered unlikely. The amount of activity injected is considered a maximum at 0.5 millicurie. From the above results it does not appear that this method could be employed to advantage over the previously described one.

DISCUSSION OF RESULTS

Some special problems encountered in the test bed operation are worth mentioning as their presence has an effect on the results obtained. The first concerns the flow of fuel during measurements. A by-pass valve, manually operated, was placed in the line on the downstream side of the apparatus, and can be seen at the right in Figure 3. This valve was operated so that the radioactive fuel did not return to the pumping system, but instead was diverted to a drum. In this way the activity was kept out of the main circulating system.

A survey of the results listed in Table 1 indicated that the return of the by-pass valve to the normal position was occurring too soon after the injection, resulting in some activity being trapped in the line - still however, on the downstream side of the by-pass valve. The result of this was to build up the background counts and thus affect the results. It was not considered practical to allow the fuel to flow into the drums continuously, as the system would have been pumped dry in a short time or the drums filled too quickly.

The second effect that caused undesirable background was the presence of the injected activity itself, which was collected in a drum which was only 6 feet away. While there was no health hazard, the very sensitive equipment employed responded to the gradual build-up of activity that occurred from the previous runs. This was apparent in the results listed in Table 3, which were obtained after several days during which activity had been used. In this case it had become impossible to measure flow rates below 3000 pounds per hour due to the increased background.

It should be emphasized that neither of the two above mentioned problems would arise in normal operation, as there would be a continuous flow of fuel through the line and the activity would be carried off with the exhaust vapours.

The most significant results are probably those listed in Table 2. The percent deviations from the mean, listed in the last column, indicate the accuracy obtainable with any given reading. Some improvement in the Geiger tube arrangement was made for tests listed in Table 3 with no significant improvement in accuracy. It is felt that little more can be gained from this approach.

Radioactive disintegrations obey a statistical law and therefore in dealing with a radioactive substance, the limiting factor as far as accuracy is concerned is statistics. In this experiment, the accuracy in the detection mechanism depends in part upon the rapid increase in count rate as the activity approaches the detecting area. This in turn depends entirely upon the profile of the activity as it proceeds along the fuel line. It is probable that at low speed this profile differs from that present at high speeds.

A source of error in every measurement is the spread in injection times. The e.m.f. induced in the coil located on the piston depends upon the rate at which lines of force are cut. This in turn depends upon the speed with which the piston descends and therefore on the air pressure. Laboratory tests indicate that the spread in injection time is less than 1/2 millisecond.

A frequency histogram has been plotted in Figure 8 illustrating the distribution of error for the results in Table 2. (From this diagram it is seen that half the errors lie within 4 percent of the mean value). The errors are obtained by determining the deviation of each recorded count from the mean value and are tabulated in the final column under the heading Percent Deviation.

At the bottom of Table 2 a comparison of calculated flow with Rotameter reading is given. Here it is assumed that the Rotameter is the true reading. With the zero correction of Figure 6 applied, the comparison between Rotameter reading and the radioactive flow gauge are given in Table 5.

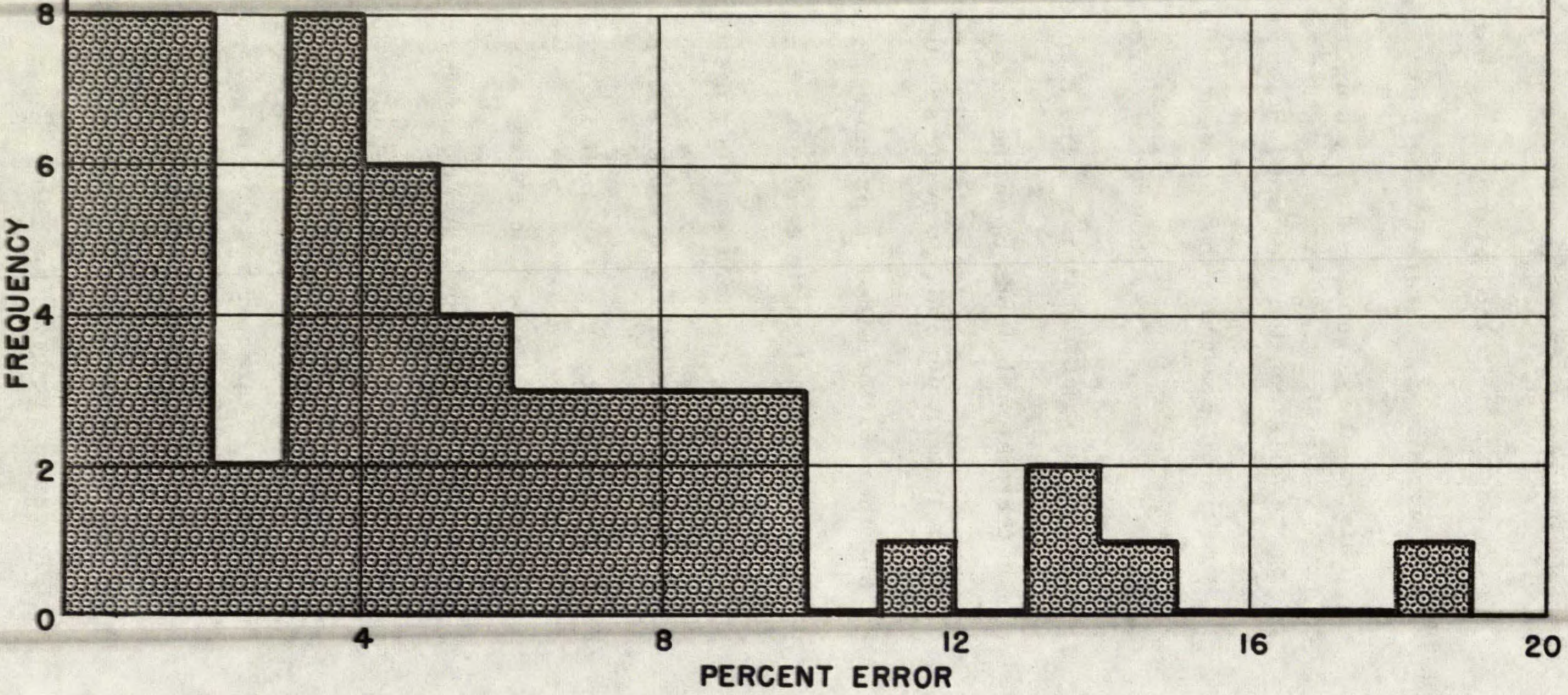


FIG. 8 – FREQUENCY DIAGRAM FOR RESULTS IN TABLE 2.

TABLE 5

Results of Test Run No. 2 with Zero Correction Applied

Rotameter lb/hr	Average Recorded Count corrected	RA Flow Gauge lb/hr	% Difference
1000	53240	1140	+ 14.0
1000	45390	1340	+ 34.0
1450	34380	1760	+ 21.3
2030	26800	2260	+ 11.3
2480	23770	2540	+ 2.4
3020	20040	3030	+ 0.4
3480	18210	3330	- 4.3
3990	16230	3740	- 6.3

A curve showing the relation between Rotameter reading and flow gauge measurement for the results of Table 5 is given in Figure 9.

It may be noted in Table 5 that the large percent differences occur at the lower flow rates. This would indicate that the simple assumptions made in the calculation of the flow rate from the recorded count are not valid at low speeds. It is probable that the velocity profile across the tube would account for this, but forward diffusion may also play a part. A further indication that a linear relationship between Rotameter reading and calculated flow rates does not exist is given by the fact that the curve in Figure 9 is not a straight line.

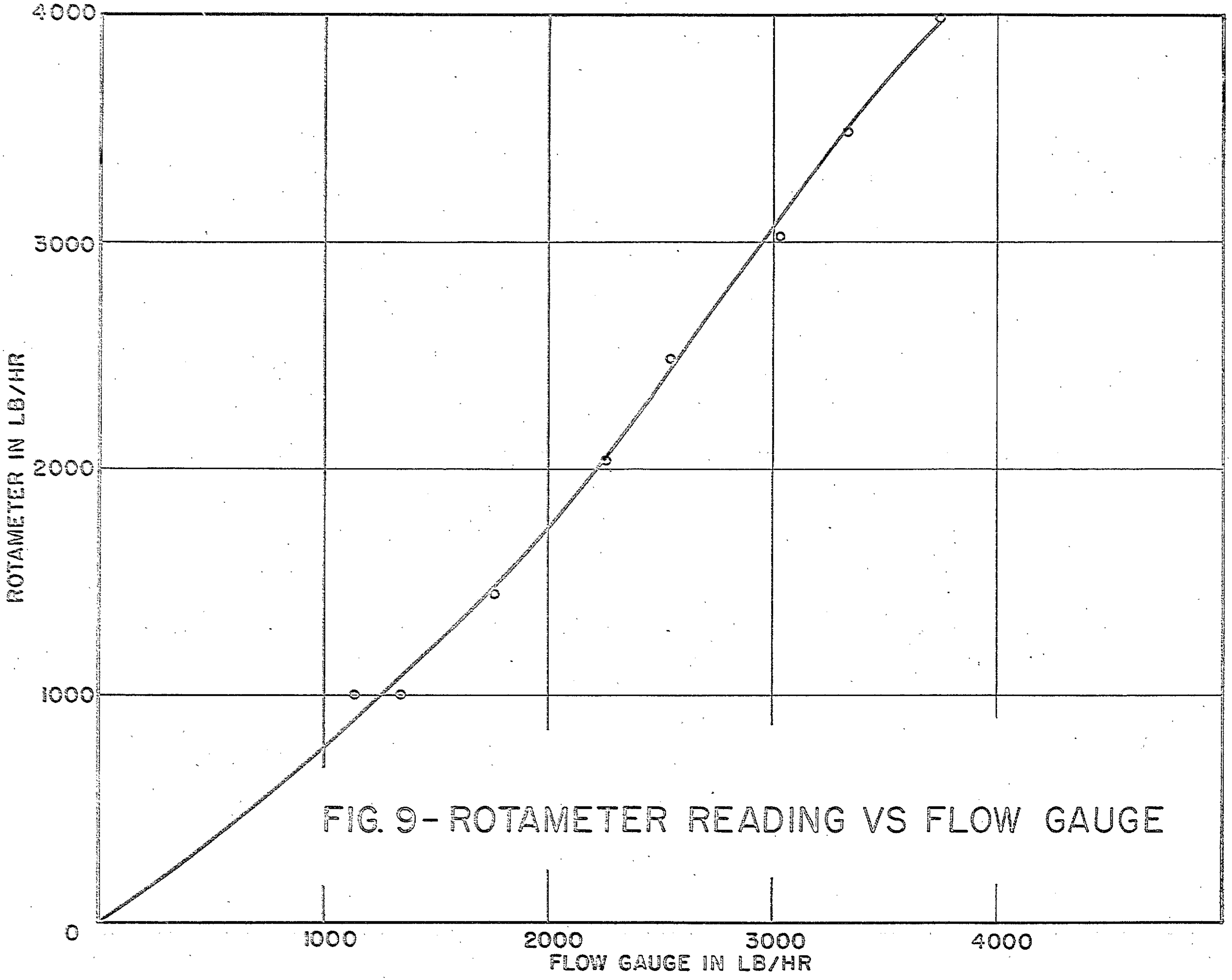


FIG. 9- ROTAMETER READING VS FLOW GAUGE

CONCLUSIONS

In test bed operation as described above, the radioactive fuel gauge has not measured up to requirements of one-half percent accuracy for every reading. There are indications that a considerable improvement could be obtained under more realistic conditions, but there is no real evidence that the desired accuracy can be squeezed out of the method.

With the present apparatus, the total quantity of activity required for approximately 40 full injection tests is 20 millicuries. This is not excessive by radiation standards, but does require careful handling and the minimum of exposure. It has been shown that at lower speeds - 2000 pounds per hour - it is certainly possible to inject less than 0.4 millicurie. However, it was not possible to increase the flow rate beyond 4000 pounds per hour so that no inference can be made concerning the minimum required at 10,000 pounds per hour.

ACKNOWLEDGMENTS

Appreciation is expressed for the aid in the chemical problems provided by Dr. H.P. Dibbs of this Section and for the help of Mr. A.F. Seeley in the construction and operation of the mechanical components. Tests were done with the active advice and cooperation of Dr. E.P. Cockshutt, Mr. G.G. Levy and the staff of the Engine Laboratory of the National Research Council. We are particularly indebted to Mr. D.K. Waffle for his help in operating the test bed assembly.

REFERENCES

1. D.E. Hull, A New Principle in Flow Measurement, Int. J. Appl. Rad. and Isotopes, 4, No. 1/2, 1, 1958.

2. J.D. Keys and G.E. Alexander, A Gated Oscillator Circuit for the Measurement of Short Time Intervals, Mines Branch Internal Report MS-59-8 (in press).

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